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WELCOME!

On behalf of the faculty, staff, and students of Northern Illinois University’s College of Engineering and Engineering Technology (CEET), I am extremely delighted to welcome you to our Senior Design Demonstration Day. CEET is hosting this event to recognize the accomplishments of our engineering and engineering technology seniors and to showcase their project demonstrations. This brochure of abstracts represents the design projects they have been working on all year.

The Senior Design Program is the pinnacle learning experience in an engineering student’s undergraduate education and represents the hallmark of success for seniors. Under the mentorship of faculty and industry professionals, the Senior Design Program engages students in a meaningful experience by bringing together concepts and principles learned in the engineering curricula, extending theories to practical application, and ultimately culminating in the construction of a prototype and/or process. In this program, an emphasis is placed on learning the design process within the framework of a design team, while a particular focus in the design experience is placed on the creation of products that can be commercialized or put into practical use to improve an industrial process. The experience students gain is comprehensive and reflects all aspects of engineering design and industry practice, including how professionals communicate ideas, how intellectual property impacts day-to-day engineering operations, and how ethics influences engineering decisions. Problem solving for open-ended complex and, sometimes, an incompletely defined system, is the ultimate challenge faced within this experience and, in its successful completion, the design is often viewed as a student’s first professional achievement.

If you have questions about any of our degrees, and/or programs in the College of Engineering and Engineering Technology, please feel free to contact me directly.

Sincerely,

Donald R. Peterson, Ph.D.
Dean and Professor of Mechanical Engineering
## Projects by Department

### Industrial and Systems Engineering

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<tr>
<td>ISYE 1</td>
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<td>Meshal Aizzliesedi, Shobhit Deshlihira, Harsh Khatri, Munther Mahmud</td>
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### Engineering Technology

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<td>TECH 1</td>
<td>Automatic Carousel Inspection System</td>
<td>Austin Rosinski, Huey Jackson, Amir Mashayekhi</td>
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<td>Jacob Bostick, Nicholas Bowgren, Landon Brown, Carlos Perez-Alvarez</td>
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<td>Matthew Kleszynski</td>
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<td>Aayush Patel (ME), Ronak Shah (ME), Alex Willis (ME)</td>
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<td>Jack Nielan (ME), Havik Patel (ME), Ryan Chatterjee (EE)</td>
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<td>Fahad Alqahtani</td>
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<td>Fahad Alqahtani</td>
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<td>Adrian Sanchez Alba (ME), Samantha Symonds (EE), Elizabeth Busby (ME)</td>
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<td>Perfusion Bioreactor</td>
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<td>Jake Lloyd (EE), Dylan Drake (EE), Nora Finegan (EE), Mercer Mack (EE)</td>
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Increasing Production Rate of Laminate through Process Efficiency

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Abstract—For this project, a student team was assigned to a local manufacturer to demonstrate the engineering tools and skills being taught in the Industrial and Systems Engineering department at Northern Illinois University. The manufacturer, Nobelus, is a value-added reseller of laminate rolls that is interested in increasing production throughput through investigating and addressing any inefficiencies and bottlenecks in their current process. Production processes will be investigated to determine areas for improvement and a current state of production will be developed for the company. Data-driven recommendations will be formulated for Nobelus as well as an initial plan for how these strategies should be implemented. Through implementing recommended strategies, the student team hopes that Nobelus can make significant progress in reaching their throughput goal.

Keywords – 5S, capacity planning, time studies, bin-packing, layout optimization, process improvement

I. INTRODUCTION

Nobelus is a value-add processor of laminate film located in Schaumburg, Illinois. Nobelus sells custom and specialty laminate products to several companies and industries, with short turn around rates. Nobelus uses MSI to measure output, where 1 MSI is 1000 square inches of laminate.

II. PROBLEM DESCRIPTION AND STATEMENT

Production targets for Nobelus are expected to increase this year, and the company must find ways to increase production capacity accordingly. Since demand is somewhat seasonal, production capacity must be balanced to keep costs low while maintaining their short turnaround times. Nobelus currently has an average throughput of about 3,500 MSI/hour and would like to increase throughput to at least 10,000 MSI/hr. The objectives of the project include:

- Reduce Non-Value Added time through minimizing movement and Non-Value Added tasks.
- Minimize downtime between runs through process efficiency.
- Improve raw material quality

III. METHODS AND MATERIALS

A. Time Studies

Time studies were performed at each slitter station to develop a current state of production capacity and processing rates. These studies also identified setup times as a large area of opportunity for potential improvements. Average percent time distributed per type of work can be seen in Figure 1.

![Figure 1. Time Study Average Work Distribution](image)

TABLE 1. 5S AUDIT AVERAGE SCORES

<table>
<thead>
<tr>
<th></th>
<th>Slitter 1</th>
<th>Slitter 2</th>
<th>Slitter 3</th>
<th>Slitter 4</th>
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<tr>
<td>Sort</td>
<td>62.5%</td>
<td>62.5%</td>
<td>56.3%</td>
<td>93.8%</td>
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<td>Set-in-order</td>
<td>45.0%</td>
<td>47.5%</td>
<td>42.5%</td>
<td>72.5%</td>
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<td>57.5%</td>
<td>55.0%</td>
<td>50.0%</td>
<td>60.0%</td>
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<tr>
<td>Standardize</td>
<td>55.0%</td>
<td>55.0%</td>
<td>55.0%</td>
<td>55.0%</td>
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B. 5S Audits

5S audits were conducted to assess the current states of each Slitter and identify areas for improvement. Audit scores will also provide a current baseline that can be used for future comparisons. Average scores per station are shown in Table 1.

C. Capacity Analysis

Historic demand information was used to provide insight into demand trends and Nobelus production throughput in past months. As the demand trends are seasonal over the course of the year, the focus for production requirements will be placed on the periods of highest demand.

D. Bin Packing

While the historic data contained much information about production outputs, data about inputs was not in a format that the student team could use, so a bin packing algorithm was used to assume master roll usage. A visual representation of the program’s functions can be seen in Figure 2.
IV. Solution Approach

A. Runner Position

Since Nobelus has significant setup and post-process times compared to machine run times, a runner position was suggested to help with setup and decrease average cycle times. The runner will be a position that redistributes some setup tasks between the operator and themselves, with these tasks being performed in parallel, decreasing average total cycle times, as visualized in Figure 3.

B. Andon Lights

To improve visual communication across the production floor, the implementation of Andon lights at each station was suggested. Once a policy for the lights is set, miscommunications and response times from other workers should be reduced.

C. Defect Forms

To combat the quality issues of raw materials, defect forms were created to begin collecting better information about poor quality master rolls. This information can later be used to make decisions about vendor material quality. A sample defect form is shown in Figure 4.

D. Facility Layout Suggestions

With data collected so far, initial calculations for a new layout were made using Distance Flow Analysis algorithms to minimize movement of workers and materials. These layout planning algorithms can also be used to plan the location of any future machine changes or additions.

V. Discussion of Results

A. Spaghetti Diagrams

Spaghetti Diagrams were created to analyze the impact the runner has had on the operator’s movement. It can be seen in Figure 5 that the station operator had a reduction in movement of about 60% due to the runner. This should mean that the operator now has more time to focus on their station instead of moving across the production floor.

B. Capacity Planning

With information collected through the capacity analysis, a tool was created for simple capacity planning. This tool would use estimated hourly MSI rates per machine and would determine any staffing changes, overtime hours, or other throughput improvements needed to achieve production targets.

VI. Conclusions

The student team determined some of the largest opportunities for improvement in throughput were in machine setup times and quality of input materials. The main solution strategies of the runner and tracking quality should result in improved cycle times and increased overall average throughput.

Currently, the runner position has been implemented and is in training, which has made initial improvements to slitter cycle times. Nobelus also had an opportunity to use defect forms to address vendor quality and receive material credit.

VII. Acknowledgements

Thank you to the NIU Department of Industrial and Systems Engineering, as well as Dr. Christine Nguyen and Dr. Purushothaman Damodaran for guiding and supporting us throughout the project. Thank you to Kurt Paquin, Steve Schaumburg, and the Nobelus staff for making this project possible.
We would like to thank Motorola Solutions Inc. for sponsoring this project.

If you are interested in learning more about this project, please feel free to contact either Dr. Purushothaman Damodaran at pdamodaran@niu.edu or Dr. Christine Nguyen at cnguyen@niu.edu. You can also contact the department at isye@niu.edu.
Improving Work Order Visibility and Trackability in the Materials Lab

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Abstract—Our capstone project was sponsored by SKF Tool. SKF is in Elgin, IL and they produce products, solutions, and services for rolling bearings, seals, services, and lubrication systems. The project’s scope is in their material labs where they receive work orders to test compounds. Currently, the material lab has no tracking or real visibility of the work orders. Some data is collected in each lab, but they are redundant and at times, inaccurate. This is due to the multiple tools used throughout the labs, but the information is not shared across the labs or tools. Continuously doing this will increase lead time, overwhelm workers, overuse the tools, and limit the departments from making continuous process improvement systems integration. In addition, they have no reliable data to fully understand their workload and the progress of the work orders through the labs. We created a Value Stream Map ("VSM") of their current state and propose a new VSM with recommendations for an improved method of data collection and work order tracking. Our goal is to document the current process, reduce redundancies, and provide a data collection process that will allow them to better understand their labs’ performances.

Keywords—Heat Map, Spaghetti Diagram, Value Stream Map

I. INTRODUCTION

Our team was responsible for observing the workflow and processes in the materials lab at SKF. The materials lab receives work orders to test compounds. There are five different labs that involve the material process: the Sirvene Lab, Mixing Lab, Analytical Lab, Curing Lab, and Oven Room. Within these labs are six different tools in use: Enterprise, SharePoint, Excel, Sirvene Lab Request Form, Sirvene Lab Data Sheet, and Analytical Lab Sheet. Upon inspection, some of the data collected during the workflow is redundant, and at times, inaccurate. This is due to workflow issues, namely improper usage of data software tools throughout the labs. The software and tools used throughout the company have the same functionality as one another, but workers were either not aware or it was simply too much work to move already completed assignments from one program to another. Based on interviews, the employees express that they feel overwhelmed with all the different tools being used, which we believe is the reason for the improper usage of the tools by the department as a whole. With data collected across multiple tools and zero integration between them, the labs are unable to make continuous process improvement or system integrations. There is little understanding of how each lab performs and how the department performs.

II. PROJECT OBJECTIVE AND SCOPE

Our objective is to improve data collection by minimizing resource usage and increasing visibility of work orders. In addition, our team will create a current and potential value stream map for the workflow process. Finally, we will try to make a visual aid to track the work order flow through digitalization of data and completed assignments.

The scope of the project includes all work order process information collected in the different labs: Sirvene Lab, Mixing Lab, Analytical Lab, Curing Lab, and Oven Room. On the other hand, ingredients that go in the compound, how to conduct the tests, and the time it takes to create the compound are the outside our scope.

III. METHODS

The team applied the Kaizen method to look for areas of waste and develop improvements throughout the workorder process.

A. Observations and Interviews

To understand the process, we followed the life of a workorder being created. At every step of the process, the information recorded and method of collection, electronic or paper, was documented. The data collection tools were studied, and we documented all the uses of them from each department. After that we created an “8 wastes of lean” chart to show different problems throughout the process as shown in figure 1.

![Figure 1 - Different Kinds of Waste](image)

B. Spaghetti Diagram

Distances between operations were measured for the entire process. Like the time studies, these distances were mostly...
focused around the different labs. Some distances were calculated to be zero because the operation was done in the same central unit. As shown in figure 2, a spaghetti diagram showing the travel done in one workorder cycle.

**FIGURE 2 - SPAGHETTI DIAGRAM**

C. Time Studies

In order to understand the timeline of work orders and how they're distributed, we divided the entire process into individual procedures. After this, the team collected cycle times—times it took the workers to go from one operation to the next. This data was later put in as the third component for stream mapping of the work order process.

D. Value Stream Map

A value stream map is an analysis method for formulating a current and future state of a process, involving the genesis of the product and its process and how it gets to the customer. To improve workflow throughout the company, we created four VSMs (two present and potential) that will target time wasting operations and cut down on time wasted. The current stream map for one of the processes is shown in figure 3.

**FIGURE 3 - CURRENT STREAM MAP**

IV. RESULTS AND CONCLUSION

Due to multiple tools being used, the team looked for different ways the data collection tools could be reduced. The method that stuck out the most was accessing SharePoint across the SKF team; effectively building a dashboard for better transparency of the work orders. Further improvements include having QR codes. The QR codes will link to the information (such as test results) for the work orders, so it is faster for workers to access key information. All the work forms such as ASR, SLR, SLDS, and CSR form will be accessible to all employees as well as any updates that might be made. Future work can be made to streamline workflow via custom software solutions and add-ons tailored to workflow. Data collected from our preliminary changes can assist in the creation of these bespoke toolsets. Our new potential process is as shown in figure 4.

**FIGURE 4 - FUTURE STREAM MAP**

ACKNOWLEDGEMENTS

We would like to offer our sincerest thanks to the Northern Illinois University Department of Industrial and Systems Engineering faculty. Special thanks to Dr. Gary Chen, Dr. Purushothaman Damodaran, and Dr. Christine Nguyen. We would also like to thank SKF for sponsoring this project, as well as Rick Webb and the many employees of SKF for their guidance and support.
Abstract—Additive Manufacturing (AM) is an advanced manufacturing process in which units of material is added in a predefined sequence to build an object. Although deemed to be a highly autonomous manufacturing process, building failures in AM are not uncommon due to improper designing factors such as intricate geometric features and small dimensions. To address this issue, a case study has been conducted with lattice structure as it presents the most challenges, especially for the FDM process. Experimental lattice designs were created at different geometry patterns and dimensional sizes. The designs were sliced with commercially available software to obtain each individual layer for analysis. The area infill percentage and number of breaks for various feature type and dimension are measured and recorded. Data analysis on the recorded information is performed to observe patterns and trends. Based on the results, a set of design for additive manufacturing guidelines for the FDM process are proposed.

Keywords- Additive Manufacturing(AM); lattice structure; tool path, manufacturability

I. INTRODUCTION

The most widely used AM process is Fused Deposition Modelling (FDM). FDM has a significant advantage over other methods because it is low equipment and material cost. FDM uses a spool of thermoplastic filament, which is melted and extruded through a nozzle on a surface in a predefined sequence. However, it does not achieve the highest geometric accuracy among all AM processes. FDM is also prone to a lot of manufacturing geometrical limitations. This project focuses on exploring the geometrical manufacturability of the FDM process, and further proposes Design for Additive Manufacturing (DfAM) guidelines. This project chooses the lattice structure design for the case study. Lattice structures are a type of geometry that is made of repetitive element cells. Programmable mechanical and physical properties made lattice structures find various application in different fields. An example for lattice structure design is shown in Figure 1. The introduction of AM has allowed easier production of lattice structures compared to the traditional manufacturing methods [1].

II. LITERATURE REVIEW

In 3D printing, there are different toolpath patterns to fill the area of the 2D layers. The most commonly used tool path patterns are: Hilbert Curve [2], Rectilinear [3], Contour [4], and Spiral [5].

Understanding impact of toolpath pattern on the manufacturability of different shapes of geometry at different dimensional sizes is the main goal of this case study. Similar challenges have been addressed for bars and overhangs by Fernandez et.al (2015). This study was focused on three characteristic geometric features: overhangs, angles, and bridges, which are 3D features [6]. In this work, we focus on studying 2D geometry features from the slices of the 3D part design.

III. PROJECT DESCRIPTION AND SCOPE

This project aims to address the manufacturability limitations of the FDM process and to formulate DfAM guidelines. Based on these guidelines one can determine the probability of the design being manufactured without any failures. Example of such error is shown in Figure 2.

![Expected Feature Cross Section](image1)

**Figure 2. Expected Feature Cross Section for a Square of 1mm(Left) Compared to the Obtained Tool Pass(Right)**

Although there are many different types of AM processes, within the scope of this project the FDM process is studied. In this project, all the process parameters and material selection are kept constant. The filament material chosen for printing is the commonly used Acrylonitrile Butadiene Styrene (ABS). The filament diameter used is 1.75mm and the nozzle diameter is 0.4mm. Overlap is set to 0mm, bead width is 0.45mm and layer height is 0.05mm. The project is also limited to the study lattice structure geometries. The guidelines created are based on the model geometry, dimension, and toolpath pattern selection.
IV. PROJECT OBJECTIVES

The objective of this research is to propose DfAM guidelines of the FDM process through identifying the manufacturability limitations in lattice structures printing. By the end of the research, the following sub-objectives will be achieved:

- Propose manufacturability evaluation metrics
- Identify geometry limitations
- Propose geometrical design guidelines

V. METHODOLOGY

A. Element geometries identification

A lattice structure can be a combination of different features of different shapes. By observing 2D layers of those lattice structures, it could be concluded that there are generally two element 2D geometries in the layers, walls and islands as Figure 3 shows.

**Figure 3. A. The 2D Wall feature, and B. The 2D Island feature**

B. Data Collection

With the identified the major toolpath types and element geometries of 2D layers, to formulate the design guidelines, the connection between the two will need to be identified. The infill area percentage and number of breaks in the toolpath is proposed to be the manufacturability evaluation metrics. The larger the infill area percentage, and lower the number of breaks, the better the manufacturability. By collecting data related to different toolpath types, for the two element features, we can observe trends in the collected data, from which we can formulate guidelines. The layer height, layer number and bead width information are collected. The toolpath images were taken from Slic3r PE. Infill area was determined by converting the tool path image to a binary image and finding the respective area using ImageJ. Infill area percentage, feature size, and number of breaks data was collected and later analyzed using Minitab 19. An example respective to data set (Table 1) is shown below.

Table 1. Example data set

<table>
<thead>
<tr>
<th>Size</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infill Type</td>
<td>Spiral</td>
</tr>
<tr>
<td>Fill Area (mm^2)</td>
<td>14.076</td>
</tr>
<tr>
<td>Area of island</td>
<td>16</td>
</tr>
<tr>
<td>Fill Area %</td>
<td>87.975</td>
</tr>
<tr>
<td>Bead Width (mm)</td>
<td>0.45</td>
</tr>
<tr>
<td>Breaks</td>
<td>12</td>
</tr>
<tr>
<td>Layer Height (mm)</td>
<td>0.05</td>
</tr>
<tr>
<td>Layer No.</td>
<td>255</td>
</tr>
</tbody>
</table>

VI. RESULTS AND ANALYSIS

The data obtained from the previous sections are analyzed and plotted as Figure 4 shows. From analyzing the plot the following DfAM guidelines for FDM process are formulated:

- The minimum manufacturable island geometry size is 2-4 mm.
- The minimum manufacturable wall geometry sizes are 1.7mm and 2mm for square and hexagon shapes respectively.
- Rectilinear presents the best manufacturability over other toolpath patterns.

ACKNOWLEDGMENT

The authors would like to thank Dr. Niechen Chen with the Department of Industrial and Systems Engineering at Northern Illinois University. We would also like to thank Dr. Purushothaman Damodaran for giving us this opportunity to work at NIU.

REFERENCES

Improving Bergstrom Zone 12 Layout Efficiency and Part Accessibility

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Abstract—Bergstrom Inc. is a company located in Rockford, IL that specializes in making heating, ventilation, and air conditioning units for vehicles ranging from mining equipment to school busses and semis. Our focus in this project is Zone 12, which specializes in assembling small water valves and controls that are shipped to customers or used throughout the plant. Due to product variation and poor zone orientation the zone has been experiencing low productivity, lack of consistency and excess motion. The goal of the project is to improve the zone’s efficiency and part accessibility. In this project, we use various Industrial and System Engineering tools to investigate the current state of the process and identify the root of the problems by collecting and analyzing data to propose solutions. Automation solutions were proposed to reduce non-value-added and essential non-value-added activities. Also, a comparably better layout was designed to addresses the inefficiencies and excess motion., reducing the average travel distance by 52.71%.

Keywords-component; layout design, spaghetti diagrams, capacity analysis, automation

I. INTRODUCTION

Bergstrom, Inc. is a company located in Rockford, IL that specializes in making HVAC units for vehicles. The company is over 65 years old and has become a world leader in the business. They have devoted themselves to lean manufacturing methods and continuous improvement solutions. This mindset is one of the main reasons the company was willing to take on a senior design project through NIU. The goal of the project is to redesign and optimizing Bergstrom’s Zone 12. Originally, Zone 12 was in a small room in the front of the factory but, as demand grew, it relocated to the center of the plant floor due to the units being used throughout the factory. Since it has moved locations about 12 years ago, the layout has not been updated or improved to fit their current needs. Zone 12 is divided in half to build control and water valve units because they are both high volume and physically small. Zone 12 needs a redesign because the current layout does not reflect the zone’s throughput, and the zone never became implemented into the plant wide Kanban material replenishment system. Due to a lack of resources, Zone 12 has been forgotten and our project hopes to change that.

II. PROBLEM DESCRIPTION

Due to product variation and poor zone orientation, the product assembly process lacks efficiency and consistency leading to low productivity and unnecessary motion that can be improved through new layout implementation.

Currently, Zone 12 has 12 stations utilized to make both water valves and controls (6 for each). Stations make different products with different sets of tools. However, similarities exist across the stations. There are 5 operators in Zone 12: 3 for controls and 2 for water valves. Therefore, the operator to station ratio is 5:12, making 7 stations unutilized while operators are working.

In addition, the parts in Zone 12 are not on the facility’s replenishment system, causing the operators to spend non-value-added time on filling up part order requests. The parts in Zone 12 are stored in a central area further away from the stations. Thus, operators have to move constantly to retrieve parts. If operators reject any product, they do not record it. Instead it is reworked immediately. However, external rejects (rejected by the customer) are recorded, but the scope of our project will not cover it, and it will not cover the shipping process either. The scope of our project includes layout improvement through redesigning, adjacent zones that might be affected (Zone 18 is the only adjacent zone), automation opportunities and ergonomic improvements.

III. OBJECTIVE

The overall goal of our project is to redesign and optimize Zone 12 to increase efficiency and reduce waste. We also hope to upgrade the parts presentation to display the parts in an easy and accessible manner to the operators. In the current layout, the parts are not located near the operators, and there is excess travel within and outside of the zone to retrieve parts and materials. In our improved layout, we will optimize material flow and reduce excess motion and activities. To further improve delivery of parts, we will analyze how to prepare Zone 12 to be on the plant-wide material replenishment system, so the operators do not have to spend time ordering their own parts.

IV. DATA COLLECTION

Before beginning the analysis process, data had to be collected to make data-driven decisions. The data collected include: time studies, motion studies, and demand data; using stopwatch or a Microsoft Excel sheet, laser measurer, and historical data, respectively.

A. Time Studies

![FIGURE 1 - TIME STUDIES SUMMARY](image-url)
To fully grasp the current assembly process, time studies on operators building different products were conducted. The time studies are summarized in the chart shown in Figure 1. The time studies revealed that a significantly large amount of time is spent on non-value-added and essential non-value-added activities. As a result, on average only 47.21% of the time is value-added. This data helps us identify areas of inefficiencies to investigate potential solutions. Operators spend a large amount of time retrieving parts, transporting tools, or transporting products. Also, operators spend a large amount of time retrieving parts, thereby creating non-value-added and essential non-value-added activities.

B. Motion Studies

Spaghetti Diagrams were created simultaneously while conducting time studies. Figure 2 shows an overlap of all the motion studies, each color representing a different motion study.

![Figure 2 - Current State Spaghetti Diagram Overlap](image)

The spaghetti diagrams illustrate the excess amount of motion in the zone, and the large distances traveled outside of the zone. Consequently, the average travel distance per order is 552 feet. Therefore, it is essential to create space in Zone 12 to include all the needed materials and eliminate motion outside of the zone.

C. Demand Data

Understanding the demand that Zone 12 has to fulfill is essential in the analysis process to prevent missing deadlines or working overtime. 2019 demand data was collected from Bergstrom. We found no seasonality in the historical data.

D. Capacity Analysis

Using the time studies data and the demand data, the capacity analysis was conducted to find the ideal number of operators for Zone 12. For this analysis we assumed operators have 80% productivity, each operator works 38.5 hours per week (excluding breaks and meetings), and there are 4 weeks per month. The calculations showed that Zone 12 needs 4 operators: 2 for water valves and 2 for controls. Since the current number of operators in the zone is 5, one operator can be reallocated to another zone, where demand is higher.

E. In-Station Tools

To analyze similarities and potentially merging stations, the tools in each station were recorded. Clustering was applied to find similarities in the stations. The results show that Zone 12 does not need 12 stations. We recommend reducing the number of stations from 12 to 8. As a result, the new operator to station ratio is 4:8.

V. Proposed Layout

Five different layouts were designed, using the new operator to station ratio. All five proposed layouts created space for areas outside of Zone 12 to be included in the zone. The two extreme motion studies (four total - longest distance and shortest distance for water valves and controls) were used to compare how the new layouts change the distance traveled. Table 1 summarizes the motion savings for each layout. Layout 1, shown in Figure 3, has the highest reduction.

![Figure 3 - Proposed Layout 1](image)

<table>
<thead>
<tr>
<th>Layouts</th>
<th>Average Travel Distance (feet)</th>
<th>Percent reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Layout</td>
<td>719</td>
<td>-</td>
</tr>
<tr>
<td>Layout 1</td>
<td>295.08</td>
<td>52.71%</td>
</tr>
<tr>
<td>Layout 2</td>
<td>315.875</td>
<td>27.97%</td>
</tr>
<tr>
<td>Layout 3</td>
<td>339</td>
<td>38.86%</td>
</tr>
<tr>
<td>Layout 4</td>
<td>249.35</td>
<td>41.61%</td>
</tr>
<tr>
<td>Layout 5</td>
<td>249.35</td>
<td>41.61%</td>
</tr>
</tbody>
</table>

VI. Results

Our analysis shows that with our improved layouts, excess motion is reduced by 52.71% and the new operator to station ratio is 4:8 compared to it previously being 5:12. Also, the company asked that we explore different areas of automation within the zone and we found that any potential areas that could be automated would be very costly to implement and would take many years to profit. In the future, the company should choose one of our proposed layouts, and execute as many of our solutions as possible in order to maximize efficiency and reduce waste.

VII. Conclusion

Zone 12 has many issues that have accumulated throughout the years, but our project addresses many of these problems and we were successfully able to deliver five improved layouts, as well as many other solutions ranging from low-cost easily implemented solutions to more expensive options for the longer term.

ACKNOWLEDGMENT

We would like to express our gratitude to Dr. Christine Nguyen for guiding us and providing us feedback and support during this project. We would also like to thank Bergstrom for giving us the opportunity to do this project and providing us all the needed information.
Minimization of Galvanized Steel Expedite Costs

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Abstract—The ability of a company to deliver a product or service to the customer on-time and efficiently using the required resources is critical to success. CST Storage partnered with the Department of Industrial and Systems Engineering at Northern Illinois University to address the issues regarding their fulfillment of orders and added expedite costs. For CST Storage to make and distribute tanks for consumer use, raw steel is sent to galvanizers to be treated and cleaned. The company is falling behind in their orders due to poor organization of their work tasks as well as their materials on hand. In order to catch up with customer orders and still maintain a schedule, this galvanization process is being expedited at the expense of CST Storage. This additional cost is one that can be avoided with the right plan of action. This project has studied the causes of galvanized steel expedite costs, as well as researched and designed a new Kanban system to assist management in the implementation of process changes that can deliver CST improved results of fulfilling on-time orders with a reduction in expedite costs.

Keywords: Kanban, Galvanized Steel, Manufacturing

I. INTRODUCTION

CST Storage is a division of CST Industries that sells and manufactures tanks for storage. CST industries consists of CST Storage, CST Covers, and Vulcan Tanks with the headquarters stationed in Kansas City, Missouri. The tanks that are made for CST Storage hold industrial liquids, grain, food, water, wastewaster, oil, gas, coal and much more. There are five manufacturing plants located in Illinois, Texas, Tennessee, Kansas and England. We will be focusing on CST Storage located in DeKalb, Illinois. The company makes all their tanks to custom orders and ships them all over the world. Over one hundred and twenty-five countries have been delivered tanks across the globe, making them a global leader in industrial storage solutions. For CST to easily ship the tanks anywhere, they are shipped as kits with all the pieces for the customer to put together.

II. PROBLEM DESCRIPTION AND SCOPE

In the last year, CST Industries has experienced a delay in the proper order sizes of galvanized steel parts for their tanks, resulting in spending over half a million dollars on expedited steel. When parts are not available when the order is to be shipped, there is a two-week lead time: one week to order more raw material and the second week to manufacture the parts in the plant. Once the parts are on hand, they must be galvanized. There are three main options for galvanizing parts: 1 day, 3 day, and standard. These are not for shipment but rather how much time it takes the galvanizer to coat the parts and get them back to the customer. Expediting costs occur at the galvanizer, when the galvanizer is rushed to do their job. Once these parts are shipped back to CST, they are then packaged and sent to their customers.

Currently, there is no safety stock levels purposely held at the facility. Even if only a few parts are needed, they will make an entire batch (size is predetermined by the manufacturing process) and keep the extras until they need them again. This can create unnecessary costs. If they overproduce, they must pay to store parts that they may not use again.

III. PROJECT OBJECTIVES

The goal of this project is to reduce steel expedite costs. We intend to find what parts would be most beneficial for the company to keep safety stock for. Since our main objective is to decrease the number of expedited galvanized parts, we want to keep on hand what is sold the most frequently so that CST and the plant workers are not waiting on these parts at any point. To accomplish this, we will analyze what the company has sold and look for the most popular parts or “high-runners”. Initially, we were informed that web trusses and ladder brackets are the most common parts that are sold in the tanks historically. Many of the remaining parts are engineered to each specific tank and will not likely be sold again, unless another customer asks for that specific size of tank. Since we are just focused on the galvanized parts, we only looked at the data for the parts being sent to the various third-party galvanizers in Joliet, Dixon and Rockford.

IV. METHODS

To determine what parts are should be in the Kanban system, the team needed to find the demand data. In September 2019, CST switched ERP systems and most data before that date was not available. The only remaining data available was the daily load tally’s that are recorded when a truck is sent to the third-party galvanizers. Information on the load tally’s includes part number, work order number, quantity, weight, location, and priority status. The team
assumed this data to be used as the demand data since no other data could be found. This data was then used for the data analysis phase and calculating the stock level calculations as well.

A. Data Analysis

In the beginning of this project, there was no signal or identification that there were low or no parts. It was discovered when workers went to package a part only to find they did not have enough or any of the part they needed. We were having difficulties finding demand data, so we investigated the parts that were galvanized in the last year. Shipment data from 2019 was analyzed to determine the companies order behaviors. When looking at this data, we found that the top 10 parts sent to be galvanized the last year made up 67.91% of the overall galvanized parts. Figure 1 shows the breakdown of the higher quantity parts shipped to the galvanized over the span of a year.

![Figure 1: Top Galvanized Parts](image)

We were able to recognize that the top 5 expedited parts were among the top 10 galvanized parts from the last year.

B. Stock Equations

Equation (1) was used to calculate the safety stock levels, where a Z value of 1.29, or 90% confidence level was used, \( \sigma_d \) represents the weekly standard deviation of demand and \( LT \) is the lead time to manufacture the part. The lead time was assumed to be three weeks for most parts since most parts require one week for raw material to be ordered and received, one week to manufacture, and one week to be sent out to the galvanizer to be galvanized.

\[
SS = z\sigma_d\sqrt{LT}
\]  

(1)

The safety stock equation calculates the stock to have on hand that will act as a buffer to accommodate for the fluctuations in demand. Equation (2) was used to calculate the reorder points. Equation (2) is similar to (1), but with the addition of \( \bar{d} \), which is the average weekly demand, multiplied by the lead time, three.

\[
R = \bar{d}LT + z\sigma_d\sqrt{LT}
\]  

(2)

The reorder point is the point at which the planning department should order the production of more products. At the reorder level, there is enough product in stock to accommodate for the average weekly demand for the duration of the lead time and the safety stock. The safety stock acts as the buffer should the demand increase during the reorder process.

V. RESULTS AND CONCLUSIONS

After our research, discussions and calculations, we found the most popular parts for CST and their appropriated safety stock levels. Without having the funds to find our own storage devices, we leave the company with appropriate safety stock levels, reorder points and cue cards for their own Kanban system. We will also leave suggestions for storage at a future time. Assuming their current storage is similar to the other storage solutions we have found, we calculated the amount of storage shelves and baskets that will safely hold their safety stock. The cue cards will be green, yellow and red with each part number, part location and batch quantity on the card. The cards will be laminated and either have two holes punched in them with ring clips attached or magnets attached on the back. With this, CST will be able to attach them to their appropriate storage shelves or baskets to have as a visual cue to replenish safety stock as necessary. We suggest that they assign one worker the job of checking the safety stock once a week and reporting any shortages to the planning department. The planning department will then make reorders as necessary. The safety stock levels are to be recalculated every six months as the company’s order will change and our calculations may not always be appropriate for their sales levels.

<table>
<thead>
<tr>
<th>Part</th>
<th>Monthly Average</th>
<th>Safety Stock</th>
<th>Reorder Point</th>
<th>Batch Size</th>
<th>Batch Max Inventory</th>
<th>Actual Storage Needed</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>257535-000</td>
<td>2984 15%</td>
<td>1782 90%</td>
<td>4355 80%</td>
<td>400</td>
<td>300</td>
<td>14 9900$</td>
<td>$3,992</td>
</tr>
<tr>
<td>20147-000</td>
<td>2851 50%</td>
<td>2000 60%</td>
<td>4250 80%</td>
<td>600</td>
<td>7800</td>
<td>6 5,300$</td>
<td>$4,998</td>
</tr>
<tr>
<td>257148-000</td>
<td>1102 11%</td>
<td>1046 50%</td>
<td>1854 40%</td>
<td>400</td>
<td>3600</td>
<td>4 2,300$</td>
<td>$2,998</td>
</tr>
<tr>
<td>1008054-000</td>
<td>588 40%</td>
<td>860 50%</td>
<td>1317 80%</td>
<td>600</td>
<td>2000</td>
<td>1 $192</td>
<td></td>
</tr>
<tr>
<td>1008346-000</td>
<td>380 10%</td>
<td>598 30%</td>
<td>875 70%</td>
<td>300</td>
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<td></td>
</tr>
<tr>
<td>1008141-000</td>
<td>365 10%</td>
<td>302 40%</td>
<td>706 60%</td>
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<td></td>
</tr>
<tr>
<td>1008056-000</td>
<td>291 10%</td>
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<td>260 40%</td>
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<td>1008142-000</td>
<td>244 20%</td>
<td>231 40%</td>
<td>476 60%</td>
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<td>750</td>
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<td></td>
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<tr>
<td>280077-000</td>
<td>252 30%</td>
<td>626 10%</td>
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<td></td>
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<tr>
<td>1008139-000</td>
<td>181 30%</td>
<td>100 40%</td>
<td>475 60%</td>
<td>300</td>
<td>900</td>
<td>1 $210</td>
<td></td>
</tr>
</tbody>
</table>

| Total:  | 68,200$          |

ACKNOWLEDGMENTS

The team would like to thank the Northern Illinois University Department of Industrial and Systems Engineering faculty. Special thanks to Dr. Christine Nguyen, Dr. Ehsan Asoudegi, and Dr. Purushothaman Damodaran. The team would also like to thank CST Industries for sponsoring this project, and Ernest Normand for his guidance and support.
Improving Layout and Efficiency of Assembly Area

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Abstract—Within industrial engineering, student teams are hand-picked to work on a company-sponsored project. Hoffer Plastics is sponsoring a project aimed to optimize one of their machines, which had an inefficient layout as well as high variation between processes from worker to worker. Using time and motion studies, data analysis, and 5S, we studied and analyzed the current state of the production area. Our recommendations are based on implementing lean tools like 5S+1 audit, layout improvements, and an analysis of ergonomics.

Keywords- Lean Manufacturing, Worker efficiency, Layout Analysis

I. INTRODUCTION

Hoffer Plastics was founded in 1953 by Bob and Helen Hoffer. When creating the company, they had the goal in mind to meet four core values of family, integrity, service, and trust. Hoffer Plastics soon became a leader in custom injection molding offering a variety of injection molding services. Products produced from the molding processes range from food container caps like the twist tops for baby food, engine caps for automobiles, and even drywall screws (drywall anchors). The primary focus of the project is the assembly machine liner 7 and the areas’ layout.

II. OBJECTIVE

The main objective is to increase the overall efficiency of the procedures involved with operating liner 7. More specifically, the objectives include (i) identifying and reducing the amount of waste produced and reducing the travel distance for the workers, (ii) analyzing and updating liner 7 standard procedures, and (iii) improving the layout for the area around liner 7, with proper workstations, designated areas for raw material and equipment. This will be achieved by implementing a 5S with a 5S+1 audit, that can be used to track improvements. An analysis of ergonomics will also be achieved with an added layout improvement. Lastly, the development of three layouts along with comparisons, cost analyses, and alternate configurations of the given layouts will be given to Hoffer Plastics. These layouts will not consider the moving of designated monuments by the company or consider the scheduling of machines.

III. DATA COLLECTION & ANALYSIS

A. Current State

The current layout of Liner 7 is a U-shape flow with opposite inbound and outbound sides. The flow of caps, foil, and boxes on liner 7 is shown in yellow, blue, and green in Figure 1. Totes, which are large bins of unlined caps, are loaded into Liner 7 on the tote tipper. Unlined caps are then moved by a conveyor into a sorter. The sorter orientates the caps, so they are all facing up and are ready to be stamped. The sorted caps are then moved on an in-feed to be stamped with foil, once stamped the caps are considered lined. The lined caps then go through the out-feed, into a vision station that rejects miss stamped caps. Then the acceptable caps are fed into a box or tote.

B. Spaghetti Diagrams

Spaghetti diagrams for both tote-filling and box filling operations were used to visually represent the path of the worker operating liner 7. Video footage was taken for 15-20 minutes, for both tote-filling and box-filling configurations of liner 7. The video footage and spaghetti diagrams do not show the following: scanning finished boxes, loading new tote, changing over parts, and clearing any jams. Boxes were taped and stacked on a pallet, then where scanned in bulk.

A few important observations were noticed in the spaghetti diagrams. Workers would scan taped boxes in bulk from 4 to 8 boxes or they would scan one by one as they finished a box. Another important
observation is that operators often had to take multiple steps back and forth when reloading a foil-reel on Liner 7. The continuous flow of the workers also showed long travel distances because they are forced to walk around the entire machine at times. The box shuttle is used as a desk which adds to the distance of having to walk around the machine rather than having a designated workstation.

C. Flow Process Chart

A current state flow process chart was created to identify and track the tasks. For roughly 20 minutes the operator did a total of 50 tasks. The tasks were broken down into categories of operation, transportation, inspection, delay, or storage. The operations were then broken down into value-added, non-value-added, and essential non-value-added work seen in Figure 3.

D. Ergonomics Study

The main ergonomic risk found was the repetitive motion of the operator leaning and lifting when removing a box off the shuttle. A box on the shuttle fills up every minute and varies in weight by product but is roughly around 20lbs. The operator is required to lift the box off the box shuttle and onto a taping machine. The box is pushed on rollers to be taped shut, then lifted and brought to a pallet where it is then stacked and scanned in as finished goods with varying heights that reach ~6ft. This repetitive motion lifting, walking, and stacking boxes, is also done while attending to other parts of the liner machine. 3DSSPS software was used to analyze the postures and motions. The results state there was no critical fatigue placed on the workers, but their center of gravity was not centered which creates a falling hazard.

IV. SOLUTION APPROACH

E. Applying 5S

In the first S (Sort), the goal of this was to identify and tag any equipment, not in use and or waste in the area. Each tag placed was labeled with the date, item description, item type, reasoning for the tag, and any additional comments. All tags placed were later documented in a Red Tag Log which placed the items in disposition to await further removal if necessary.

Plans for Set in Order are the implementation of a color-coded marking on the assembly floor, an adequate storage plan, and define locations for tools and equipment. For workstations around Liner 7, the goal is to have set locations for items and something to refer to the items. By implementing this, misplaced and missing items will be more obvious. After Set in Order, Shine will be started with a cleaning of the area around Liner 7. Visuals for cleaning standards in the area will be created, in addition to cleaning schedules. To implement Standardize, a standard inspection sheet will be created, along with the updating of standard work document for Liner 7. The use of visual directions will be helpful for Liner 7 because of the large number of temporary workers on shifts. Pictures of the ‘right and wrong’ will be displayed around Liner 7 to help guide temporary workers. Lastly, to sustain the system, we plan on having management enforce the changes that were made during the implementation of 5S. Management will also be responsible to follow up in performing a 5S+1 audit to monitor the area.

F. Layout Proposals

The following are brief descriptions on changes from the current state to the proposed layout:

- Proposal 1: Outgoing filled boxes changes direction causing the flow of boxes shown as arrows on box shuttle. Finished boxes can share a packing area with a machine 919. Currently, machine 919 doesn’t have a usable box taper area.
- Proposal 2: Machine 919 is moved out of the area, to another factory location. On Liner 7, Tote-tipper & Conveyor are rotated, along with the box shuttle. Liner 7 completes a proper U-shape flow
- Proposal 3: Machine 919 is moved out of the area, to another factory location. On Liner 7, the box shuttle is rotated 180 degrees. The layout has free space and is used for WIP and equipment storage against the back wall.

Proposal 2 was found to have the most improvements based on the current layout. Table 1 shows areas of improvement in proposal 2.

V. CONCLUSION

Hoffer Plastic will pick a layout to implement once cost analysis is completed. Once 5S is complete and a layout has been implemented, a 5S+1 audit will be performed to compare the new layout to the old layout.

VI. ACKNOWLEDGEMENTS

The team would like to thank Dr. Nguyen, the advisor of the team for all the help provided as well as support throughout the entirety of the project. As for Hoffer Plastics, thank you for allowing us to be a part of your team and take on a project for your company. Within Hoffer Plastics, we want to thank Sam Murad for all the help he gave us as our team leader at the company along with Jim Stoffel and Les McMichael who worked with us.
Developing an Automated Carousel System for the Inspection of Printed Circuit Boards (PCBs)

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Abstract—The inspection process is often overlooked when considering the development of a product. In order to reach market, companies spend vast resources solely on searching for faulty products to remove before being shipped out. Two main drawbacks of inspection processes are the time it takes for an operator to manually inspect a product as well as the presence of human error. Given its clear importance, we found a way to improve the procedure by using automation and image processing. We created a method inspired by current automated optical inspection (AOI) systems that inspects printed circuit boards (PCBs) to determine if and where part defects exist.

Keywords: automation, inspection, image processing, computer vision, time standards, surface mount technology

I. INTRODUCTION

The demand for PCBs continues to grow rapidly with a market value of $63.1 billion in 2017 and is expected to reach $76.9 billion by 2024. [1] With such high demand for PCBs, modern manufacturers have turned to surface-mount technology (SMT) to place small electronic components onto boards quicker than a human by using rapid-moving feeding machines. SMT allows companies to make their boards more functional and complex with the ability to place a larger volume of components onto each board, but there is still a margin of error when operating with a high number of parts in a small space.

Without a proper inspection system at place, these examination processes usually end up being the bottleneck of an assembly line as it can force idle time. [3] Companies turn to AOI systems integrated in their assembly lines to substitute human-based inspection, which are proven more efficient and precise. A typical AOI can inspect roughly 30 sq. in. of PCB per second while roughly detecting 1.5 million components per hour. It also has an incredibly accurate inspection output, with an error rating of 500 parts per million (PPM), or a 0.05% typical error. [4]

Our objective is to design a system based on an AOI’s concept while addressing its drawbacks: having a large footprint and being expensive, as some can reach over $90,000 in costs. [4] We will use image processing and computer vision to achieve the inspection aspect, create a portable and cost-effective system, have it accessible to operators, and make it interchangeable so companies can use it with various PCB operations. We will also create a sample PCB with 10 parts to test if our system is capable of finding missing or defected components on it.

II. THEORY

The peripheral aspect of our system utilizes computer vision (CV), which is the study of how digital images and video allow computers to gain a higher understanding than simple binary code. We will use an image sensor and CV to break down images into a graph of pixels.

Once the image is acquired, it is broken down into pixel and then channel. Each pixel contains three channels that each make up a color: red, green, and blue. The mixture of different intensities per channel give us the full color spectrum. [2] With the use of image processing, we can essentially train our system to break down the image it receives into pixels and compare the pixel’s intensities with arbitrary values derived from an image of a perfect PCB with no components missing. A change in intensity compared to our desired product can help us find defects on the PCB, specified as locations shown on the pixel intensity graph as a coordinate system for accessibility.

Rather than accessing each pixel, our system will focus on pixel clusters, or region of images (ROI) to inspect component areas. Not only does this alleviate strain on our CV analyzing each pixel, but it also allows imperfect parts to still pass if they are making adequate electronic connections via margin of error. Our system will then convert ROI areas into specific component numbers for an operator to easily read and determine which part is defected on the PCB.

Using a coding language and specific application programming interface for our chosen image sensor, the camera can act as the computer’s eyesight; the use of image processing is then used to break down each image gathered for more information regarding our sample PCB.
III. MATERIALS AND METHODS

A. Carousel Design

The design of our carousel comprises of three main parts: mechanical, electrical, and programming components.

For the mechanical aspect, we are using a circular tray and found it to fit up to eight PCBs with ease. It was decided to 3D print the tray for interchangeability as it could be offered to companies that run various PCB operations with different sizing. The tray is then directly mounted onto the motor with a flange mount for a lower center of mass.

The electrical side consists of three components: image sensor, stepper motor with drive, and microcontroller. We selected an image sensor based on requirements such as pixel sensitivity, frame refresh rate, and dedicated processing speed. Our stepper motor requirements were less strict as our operation does not require much torque.

Finally, our programming design intent mainly focuses on using a scripting language that can easily connect our image sensor and microcontroller to run the operation.

![Figure 2: carousel system design](image)

B. System Requirements

Because our system inspects PCBs, torque is negligible due to the low weight requirements of eight boards being inspected per cycle. To find torque (T), we first found the summation of each carousel along with our desired angular acceleration (α).

\[ T = I \cdot \alpha; \quad I = \frac{1}{2} \cdot m \cdot r^2; \quad \alpha = \frac{\text{rotation}}{t^2} \]  

(1)

Based on our carousel's goals of completing the eight rotations at one second each and torque necessities, we calculated the following:

\[ T = (7.59 \times 10^{-3} \text{ kg}\cdot\text{m}^2) \cdot (0.785 \text{ rad/s}^2) \]  

(2)

We obtained a rated torque of roughly 5.96 x10^-3 Nm which helped us select a stepper motor for the system.

C. Procedure

1. Motor turns tray so PCB reaches inspection point
2. Sensor acquires PCB image, compares to original
3. If fails, system stops / sends error data to operator
4. If passes, motor turns to next station on carousel

IV. RESULTS

To formulate results and show that our system is more efficient than a human inspection process, we used a Predetermined Time Standard (PTS) to study the motion of both inspection procedures. Our time standard breaks down each basic motion into micromotion elements. [3]

Figure 3: workstation assumption for each inspection process

Through time standards and workstation assumptions, it would take an operator 48.86 seconds to inspect eight boards, versus our system at 26.82 seconds per eight boards.

V. DISCUSSION

Based on the times for both inspection processes and assuming a workday with 7 hours of operation time, we determined that a human could inspect 3,752 PCBs per day versus our system inspecting 6,832 PCBs per day. The difference is 3,080 more PCBs inspected by our system.

VI. CONCLUSIONS

Our automated inspected system proves to inspect PCBs at a faster rate than a human. This is beneficial for a company because it saves time in the inspection process, which could be a potential bottleneck in the overall cycle time of a product. [3] Addressing this can save money in the long run through efficiency in manufacturing.

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REFERENCES


Semi-Automated Defect Detector
Sponsored by MTH Pumps

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Abstract—MTH Pumps manufactures industrial pumps. The facility in Plano, IL, is involved in constructing pumps for numerous industries such as boiler feed, water services, chillers / temperature controllers and refrigeration. The castings and covers of the pumps must go through a testing process to determine whether the parts might have a crack that will result in leaks. The new design focuses on improving the setup time of the testing process by semi-automating the setup. Aside from reducing the set-time, the cycle time between tests is also decreased in the new design. Finally, the new design increases the success rate of leak detection by relying on pressure sensors instead of sight to determine leaks or cracks within the castings or covers.

I. INTRODUCTION

Ensuring a pump can hold pressure is arguably the most important feature of a pump. Our senior design project focused on the T31 pump model. The T31 pump model is made from two bronze castings fastened together. One half is the motor cover, with the other half being the motor bracket. The current process for the inspection step utilizes a machine that consists of a large metal plate suspended above a tub of water. Eight individual part slots lay across the plate where the castings are placed. Then any drain or inlet port the casting has are manually threaded. Two posts sit opposite each part slot that a clamp and screw mechanism are slotted into. Then they are manually tightened to secure the castings to the plate. After this, the plate is dropped into the water. A small hole in each of the individual part slots sits along the fluid track of the castings and supplies pressurized air into the closed system for about twenty seconds. The operator then raises the plate out of the water and conducts the visual test.

The visual test consists of the operator observing the tops of the castings for bubbles that would indicate a defect in the casting along the fluid track where air could be escaping. The current process is very time consuming, taking 15 to 20 minutes to test only one half of a pump at a time, allowing defective castings to get through the process. MTH wants a new process with the goals of eliminating the manual labor for the process and providing automated aspects, while producing more consistent results through a more scientific testing method. This system often results in pumps reaching consumers and failing to meet their needs. Our team was assigned to design a semi-automated system, which will assist in detection of failed pumps and decrease cycle times. We selected the decay test method to satisfy our objectives, mainly because it was a quick and easy process that allowed us to easily incorporate a Programmable Logic Controller (PLC) to control the components.

Other companies also create leak detection systems, but by creating our own, we can fine tune the process to trim unneeded features. However, because a decay test is conducted the same across the board, we can use the same formulas that name-brand manufacturers use [1]. This gives our system credibility, as well as the ability to provide accurate data as a benchmark.

II. MATERIALS AND METHODS

Our prototype was designed to test two cover castings at the same time via pressurizing the air track of the castings themselves. Two pressure transducers (rated up to 100psi) were placed in the pressurized zone, picking up the current castings’ pressure. There are four Enerpac hydraulic clamps holding each casting, one on each corner. This is an improvement on the current setup where there is only one contact point holding the casting down. The castings themselves are clamped onto a surface ground aluminum plate (Figure 1), which has O-ring grooves cut out to ensure they are sealed properly. To start the system, the operator pushes two green buttons, which starts the PLC.

Figure 1
A red E-stop is placed in an easily accessible area in case of emergency or if there is a need to pause the system. Red process lights will indicate if the pressure sensors are below a set value, while a yellow process light will signify that the test is in progress. Because we will be using pressurized air and hydraulic clamps, we have two pneumatic solenoids and a hydraulic pump. The previously listed components will be placed on an industrial plastic cart (Figure 2), with the system being on the flat top, solenoids and PLC on the middle shelf, and the hydraulic pump on the bottom shelf.

One major hurdle we had to overcome was that the castings have multiple threaded ports connected to the air track. This means we had to seal them before the test was conducted. Previously, the operator had to hand thread plugs into these ports, which takes time. We solved this problem by having rubber plugs attached to the clamping arms to plug the holes at the same time the arms press down on the castings. We pressurized the castings to 25 psi. At this pressure, with an area of 11.39 in² for the air track, we needed a minimum of 284.75 lbf pressing down to seal each casting. The pneumatic solenoid could build the pressure in each casting, hold at a neutral position during the test, and exhaust the pressure once the test was completed. We decided on two transducers on each casting for sake of a fail-safe. Because we were relying so heavily on the transducers to give an accurate number, we double checked the pressures from both transducers in case one malfunctioned. In case of a malfunction, red process lights would be illuminated to inform the operator of an issue.

III. RESULTS AND VIRTUAL BUILD

The outcome of our project is to replace the manual system at MTH, but to also increase productivity. The updated system is expected to test two castings in less than 2 minutes, including charge time, settling, and work handling. This would save MTH $5,833 just in labor for testing the annual demand of the castings.

One aspect of the previous design MTH struggled with is a lack of quantitative data. The bubble method, while being outdated and prone to false positives, is good for a low-quality quick check. The decay method will be able to produce actual data that can be cross referenced against calculations and quality standards [2]. The sensors and PLC components were handpicked with both functionality and feasibility in mind during the decision-making process. While the process of determining specific data for passing and failing castings was outside the scope of our project, the new system will be able to provide an industry standard of quality control and data acquisition.

Because of the time shortage, we were not able to test the clamps or pneumatic system to determine an accurate cycle time, and thus the 2 minutes is an estimation. All components have been ordered for the system; however, some machining is still required to complete the system. MTH can machine all the components in house, reducing additional costs to manufacture. Once fully manufactured, the system will be ready to assemble and test.

IV. CONCLUSION

It is recommended that MTH decrease the manual set up and incorporate the automated features to reduce the setup time and overall cycle time of the test. Furthermore, by eliminating the vision inspection in the original test and including some pressure sensors instead, the human error is eliminated. The addition of these sensors will increase the number of ideal castings and covers distributed by MTH Pumps. Finally, for future consideration, the company can make this semi-automated process fully automated by including a robot to increase overall efficiency.

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REFERENCES

Abstract—Mobility plays a big role in our daily lives. It can take us from point A to B with little effort. Methods for mobility can refer to vehicles, bicycles, scooters, etc. For this case, we are introducing our mobility aid device, which was designed to assist walking for those with an impairment, are unable to sustain their own weight, and/or have a physical injury. We took a given design and developed a device with similar functions but with the following differences: reduction of overall cost and a redesign for easier construction.

Keywords- Walker, Wheelchair, Disability, A linker

I. INTRODUCTION

Mobility aids were designed to help individuals with difficulty getting around, people who have disabilities or injuries, or older adults who have a higher risk of falling, muscle weakness, joint problems, or are unable to care for themselves. A few of the mobility aids available today include crutches, canes, walkers, wheelchairs, and motorized scooters, but choosing one of the devices requires time and research. Each of these devices should be fitted to the person’s disability and physical condition because its sole purpose is support. A study from the University of Central Arkansas reported that out of 158 rolling walker users over the age of 65, the most common misuse was incorrect height [1]. If the device is not matched to their body type correctly, using it can be uncomfortable, unsafe, and can cause further issues.

Over the years these devices have taken on many forms, from a wheeled device suitable for indoor use to sturdier use on grass or paved surfaces. Our goal was to design a safe, comfortable, and easy to maneuver alternative to traditional aids. Factors to consider were improving stability, reduced loading and generating movement.

We were given the task of taking a current design such as the A linker (Fig. 1) and improving targeted characteristics of the device [2]. The device is a non-motorized walking bike without pedals. In other words, it is a walking trike designed for those who need minimal assistance getting around [3]. Its design is a three-wheeled bike with an arched aluminum frame connecting two 16-in front wheels with an 8-in rear wheel and an adjustable seat mounted in the middle of the dropping tube. It uses standard bicycle hardware and is designed to work with most standard accessories. It folds up at a joint near the seat, creating a compact design to slide into a trunk. The overall weight of the device is 26.5-lb and supports up to 250-lb. The design had to have similar function but with the following differences: simpler design (straight lines) for easier construction, same tire/wheel size for easier maintenance/repairs and reduced overall cost. Therefore, it was our goal to design and build a device that would be suitable for all types of terrain and help individuals be more included in society.

Figure 1: A linker

II. METHOD AND MATERIALS

Designing the frame was one of the first steps we took during our procedure. We wanted to make our mobility aid as small as possible but still true to many of the standards of modern-day bikes and mobility aids. One major objective we had to address was that it had to withstand a force of 250-lbs without distorting. The frame is made of circular tubing that has two types of diameter (Fig. 2), which increased the overall weight but made it secure and able to reach our 250-lb user goal. The front steering axle is at a 10-degree angle, increasing frame strength while allowing users’ weight to be set farther behind the front axle for reduction of stress. This makes the device well balanced when encountering bumps and rougher terrain. Additionally, a brace was integrated in the front fork for increased stability. A-513 Carbon Steel was the optimal material for the frame due to its high strength, durability, low cost, weldability and resistant to fatigue [4].

A. Raw Material:
   • A-513 Carbon Steel
   • Circular Tubing (Frame)
     • 1.125” OD*0.120” Wall, HREW tube
     • 1.000” OD*0.120” Wall, HREW tube

B. Seat Components:
   • Bicycle seat memory foam
Once we planned our final design, we were able to conduct a stress analysis study using Ansys. We set a point load at the seat post of the frame of 250-lb. We tested multiple materials with different thicknesses and diameters. This allowed us to determine what sizes we would use, and we were able to reduce the weight by using smaller and thinner materials. We found that A-513 Carbon Steel was the best for our frame because it had a maximum stress of 7328.6 psi (Fig. 3). Based on this we found that the frame would be able to support a 250-lb person. In the simulation we are also able to find the total deformation to be 0.0065 inches (Fig. 4).

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REFERENCES
Abstract—Whether it is in the classroom or on the job, temporal light modulation (flicker) affects our everyday lives. Flicker has many neurobiological impacts on our body that effect our performance. How we perceive both moving and stationary objects can also change as result of flicker. The goal of this project is to be able to detect flicker characteristics of common light sources by designing a low-cost handheld combination spectrometer and flicker meter. The flicker meter will provide some of the common flicker metrics as identified by the Illuminating Engineering Society (IES): Percent Flicker and Flicker Index. The intention of this design it to allow the user to walk into any lighting environment with this portable device and have light source data performance at their fingertips. The system will utilize the output of a Hamamatsu light sensor with data processing provided by an Analog Discovery 2 and a Raspberry Pi 3B+ (RPi) using Python language coding.

I. INTRODUCTION

Flicker affects us whether we are aware of it or not. This is a result of flicker having visual and non-visual characteristics. Flicker’s visual characteristics and impacts on our body are dependent on the amplitude and frequency of the variation [2,3,4]. Temporal light modulation (TLM) is used to describe any change in the intensity or spectral distribution [2,3,4]. TLM is characterized depending on the variation of amplitude and frequency while the term ‘flicker’ is used to reference a change in the visual perception of that variation [2,3,4]. Temporal light artefacts (TLA) include all visually perceived consequences of TLM. Flicker has been shown to have various negative effects on performance and health, as well as an increase in fatigue [2,6].

Negative Neurobiological Impacts of Flicker
Health effects due to flicker include seizures, migraines, headaches, eye strain, and reduced visual performance [6]. While flicker between 8-30 Hz has the most prominent effects, flicker above the visible threshold can still be perceived subliminally [6]. Even when flicker is beyond visible frequencies it has been shown to still result in many of the negative neurobiological impacts [2,3,6]. Since flicker is often inperceivable, it is important that there are tools to identify and describe it.

Negative Impacts of Flicker on Human Visual Perception
In addition to these health effects, flicker also impacts how we perceive moving and stationary objects as a result of TLA. This poses many concerns for our safety in industrial settings where heavy machinery requires strict safety standards and guidelines to adhere to.

II. COMPONENTS AND FUNCTIONS

Device Functions
The function of this handheld flicker spectrometer is to capture and calculate the severity of flicker in a room or on a factory floor. This process is done by first interacting and navigating the touch screen and selecting the option to measure flicker. From there the user would then point the sensor on the device towards a light source to capture the luminescence of that light source. Then the meter would graph out the data as a graph light intensity versus time. Then the user would indicate if they wanted to see flicker index, percent flicker, or both by interacting with the touch screen.

Device Components
- Hamamatsu C12880MA
- Diligent Analog Discovery 2
- 1.4 GHz 63-bit quad core Raspberry Pi 3B+
- Adafruit PiTFT 2.8” capacitive touchscreen
- Adafruit 3.7V/1.2A li-polymer battery
- Adafruit Powerboost 1000 Charger
- Aluminum enclosure
III. METRICS AND EQUATIONS

Percent Flicker
- Calculated through use of min and max points
- Measures the depth of modulation of flicker
- \[ A = \text{Max. Lux}, \ B = \text{Min. Lux} \] (Figure 3)

\[
PF = \frac{A - B}{A + B} \times 100
\]  

(1)

Flicker Index
- Calculation using integral of curve in relation to average lux
- Characterizes the intensity variation based on shape of waveform as well as amplitude
- Area of Lux vs Time (Figure 3)

\[
FI = \frac{\text{Area1}}{\text{Area1} + \text{Area2}}
\]  

(2)

Data Analysis
Using the methods above we were able to acquire many spectral readings of both an Ikea C1 LED bulb and a Compact Fluorescent bulb using both the PC and the Raspberry Pi 4 as the controlling method. These readings in figures 2 and 3 show that the circuit can capture spectral readings using a 20-microsecond exposure time which are accurate when compared with an Mk350D spectrometer. When the cycle time of the C12880MA is calculated with a 5MHz clock and this exposure time, a full capture cycle is accomplished in 104 microseconds. This allows us to potentially take readings at 9615 Hertz. This speed of capture is what will allow this circuit to be used in order to measure flicker.

IV. CONCLUSIONS
Using the C12880MA in conjunction with a Raspberry Pi 4 and an Analog Discovery 2 a device can be created which can take accurate spectral measurements and has a speed of measurement which enables it to be capable of being used as a portable flicker meter. Further development into increasing the number of readings per acquisition and the code to interpret the spectrum readings into flicker measurements can yield a compact handheld device capable of taking both spectral and flicker measurements.

Figures and Tables

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REFERENCES
Robotic Arm to Aid Schools with Robotic Based Projects

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Abstract—National and state spending on education has been a touchy subject for many years. The cost of education is rising, and the ability for schools to support new technologies is decreasing. The goal of this project was to create a low-cost alternative for schools to enhance the robotic knowledge of students and staff. This prototype arm will give teachers a user-friendly platform to teach students basic robotic concepts at a low cost to the institution. The prototype was designed using modern robotic mechanisms and an open source control platform to allow future expansion.

I. INTRODUCTION

In 2019 the United States alone, spent $13 billion on educational technology.[1] But educational technology can differ based on a student’s economic or geographic area. To minimize the gap between students and technology, I have designed and built a 3D printed robotic arm that can be used to teach and demonstrate robotic-based concepts. Automation and robotics are a thriving field in today’s society. More than 3 million industrial robots will be used in factories throughout the world in 2020. [2] Giving students the ability to work hands on with these systems is crucial. In this paper, I describe the methods that went into designing and building the robotic arm as well as a cost analysis of the project.

II. MATERIALS & METHODS

A. Prototype Design

The robotic arm was designed with 4 degrees of freedom. Each axis is controlled using a planetary gear box and a Nema 17 stepper motor. (Fig. 1) The arm was designed with expansion in mind, an end effector or another axis of rotation can easily be mounted if needed. The models were created using Inventor by Autodesk. Every component of the arm besides the control accessories and motors were 3D printed using an Ender 3 by Creality.

Amazon Basics PLA filament was used to print the arm. PLA, polylactic acid, is a thermoplastic polyester. PLA is inexpensive and durable and used in a wide range of 3D printing applications. [3] PLA holds good dimensional accuracy, which was needed when printing the planetary gearboxes.

B. Gears and Calculations

Two sizes of planetary gears were used on the arm. Dimensionally the gears are different, but the mechanical principles stayed the same. Each gear consists of three components: a ring gear, sun gear and four planetary gears. (Fig. 2) The ring gear is fixed, and the sun gear is driven by the stepper motor. Planetary gearboxes are used in robotic applications because they produce little to no backlash. The gearboxes were designed to be compact and lightweight, and many teeth are engaged at once, allowing for speed reduction and lower inertia back to the stepper motor.

The gearbox assemblies consist of a carrier plate driven by the planet gears. The carrier plate is located and controlled using steel balls. These balls reduce the load on the planetary gears. (Fig. 3) For the teeth of a planetary gear to mesh correctly, a simple formula must be followed. (Equation 1) The number of teeth for both sizes of gearboxes is shown in Table 1. These numbers were used to calculate the gear ratios for the gearboxes.
The gear ratios for a planetary gear can change depending on what component is fixed and what component is driven. The ring gear is fixed, and the sun gear is driven for both gears on the arm. To calculate the ratio, we can use the equation 2. [4]

\[
\text{Gear Ratio} = 1 + \left(\frac{N_r}{N_s}\right)
\]

(2)

\(N_r=\)number of teeth of Ring Gear and \(N_s=\)number of teeth of the Sun Gear

The 2.5inch diameter gear has a ratio of 4.25:1. This means for every 4.25 turns of the stepper motor, the gear will make one complete turn. Likewise, the gear ratio for the 3.5inch is 3.625:1. These ratios are needed to ensure the arm moves as expected.


**C. Control System**

The robotic arm is controlled by an Arduino Uno microcontroller. An Arduino is an open-source controller that allows for easy programming and add-ons. Stepper motors cannot be controlled by just a microcontroller. To control stepper motors, there must be a voltage switch from high to low or a “pulse.” To control this pulse, a driver must be installed. The drivers used for the arm were Sure Step micro stepping drives. These drives come with built-in overheating and overcurrent detection to protect the stepper motors.

**Voltage = Resistance X Current (Ohm’s Law)**

(3)

![Table 3: Cost Reduction Table](https://ifr.org/ifr-press-releases/news/robots-double-worldwide-by-2020)

**III. Cost Analysis**

To make the robotic arm available to schools, the cost must be low. The overall cost of the robotic arm ranges based on the components used. The stepper motors and drives in the prototype were rather costly but were available at no cost for the prototype. Similar drives and power supplies can be acquired for much lower costs. The cost of the prototype is roughly $400. If the arms were to be produced for sale, they could be manufactured for as little as $225. Table 3 breaks down each assembly based on cost. This price could be reduced with more refined manufacturing processes such as outsourcing the components.

**IV. Conclusion**

This paper presents the design and prototype of a robotic arm aimed to help students and staff with robotic-based projects. The arm used manufacturing processes such as 3D printing to keep cost low. The open source platform is easy to use and teach. The platform allows for growth and customization at no extra cost to the user. A future direction includes adding point-to-point programming tracking, which will allow users to store arm positions and play them in sequence.

**Acknowledgment**

This work was completed with the support and guidance of Dr. Andrew Otieno and Joseph Bittorf.

**Reference**


Abstract— Programmable Logic Controllers, or PLCs, are devices used to control anything from simple LEDs to complex industrial systems through an easy-to-use logic program. The purpose of our project was to create a 3-axis motion controlled mechanism commanded by PLCs that can be used to move objects from one point to another. This was done with 2 stepper motors connected to lead screws that in turn moved slides, along with an electric piston actuator with an electromagnet connected to the end. The two stepper motors were used to move the piston along an X- and Z-axis to position it above an object. The actuator was then activated to lower the electromagnet in the Y-axis direction, to the object, energize the magnet, collect the object, and raise. The slide system then moves the piston and object to another point, lowers the object, releases it, and retracts to the starting position. This mechanism can be used for demonstration purposes to educate high school students about the uses of PLCs and how they are programmed. It will also be used in the Automation class to implement motion control applications.

I. INTRODUCTION

The purpose of this project was to create a demonstration model to show the intricacies of Programmable Logic Controllers (PLCs) and some of the uses they might have. This model was aimed toward an audience of high school students, so its main purpose was to simply show them how a PLC works. While there are other PLC demonstration models on the market, those models only contain simple switches and LEDs, limiting the usage of a PLC. Our design includes moving parts to help not only captivate the audience, but also show more of the complex uses of the PLC while keeping it a simple demonstration. In addition, this model will be used for instruction in motion control applications.

To make our demonstration model (demo), we decided we wanted to replicate a simple crane machine, like the ones filled with toys at supermarkets. Using those machines as a reference, we realized we needed something to grab objects and to be able to move that grabber along three different axes. We concluded that the best way to move in three linear directions was to use three linear actuators. Two of the actuators are stepper motor driven actuators (slides) and the third is a piston-like electrical actuator (piston). The two slides were set up to move along two of the three axes, X and Z, covering movement to the left, right, forward, and backward. That left the remaining piston to move up and down along the Y-axis. Lastly, for our grabber, we chose a simple electromagnet that was attached to the end of the piston. This meant we need a ferromagnetic material for our objects, such as iron, steel, or other magnetic metals. After some discussion, our best option was small steel blanks available through the university machine shops.

Once we combined all three of the actuators into one mechanism, our next step was to create a program that would move the actuators to a desired position. Since we were working with a Productivity 2000 Series PLC, we used the accompanying software, Productivity Suite, and the ladder logic. We wanted the actuators to move on command, so we controlled them with push buttons and some physical limit switches. For safety reasons, we also planned to incorporate a safety switch to shut the entire system down, along with translucent safety covers for the demonstrations. Since the stepper motors need pulses to move, [1] we also used step drivers provided by the university to help control movement of the motors.

II. TECHNICAL METHODOLOGY

The first part of our project was the program. The main objective of this program is to send electrical signals to the stepper motors and piston to make them move on command. The original program we were given at the start of the project did not communicate the move commands properly. We then tested the command with a sample program from Automation Direct, along with some new programs we wrote from scratch. Eventually, we decided to start from scratch instead of keeping the original program. Once we did, we were able to learn the proper programming to set up the move commands and both of the motors moved on command. With this breakthrough, we moved on to wiring the mechanism.

We started by connecting both step drivers to the link for the PLC based on the wiring schematic (Fig. 1) for the first driver and copying it for the second. After the step drivers were wired into the stepper motors, we wired the control push buttons, the start switch, and the safety switch. To prevent confusing the buttons and switches, each pair of buttons (corresponding to each axis of motion) were wired with different colors, along with different colors for the switches. We also labeled all of the wires to make sure we could consistently reassemble the system without trouble.

Our next step was to design and build a frame for the mechanism to rest and operate on. The design (Fig. 2) was simple so assembly and disassembly could be streamlined, and storage would be less problematic. Once the frame was assembled, we mounted the mechanism and wired the entire system for testing. Once we finished multiple rounds of testing, we were able to move forward with the next step of the project: designing the safety features.
With the project nearing its finished state, all that was left was to design, create and implement the necessary safety features so no one could get hurt during a demonstration. These safety features (Fig. 3-4) were planned to be made from sheets of clear acrylic so the project and all of the components, both electrical and mechanical, would be visible for the audience. We wanted to make sure everyone could have a good time while also staying safe.

### III. Conclusion and Recommendation

The main objective of our project was to design a 3-axis motion controlled pick and place system. This was done by taking three linear actuators, two slides and one piston, and orienting them so they could move freely as one coherent mechanism. This mechanism is controlled by a PLC program, which is set to drive the mechanism on command. The mechanism is then mounted to the top of a frame constructed of t-slotted railing. From there, the mechanism can act as a crane machine by moving into position on command over an object, picking the object up, and moving it to a new location.

One of our highest goals of this project was to make our demonstration model reproducible. Our project is being made with very expensive parts because they were available to us at no cost, but we would not suggest using the exact same parts in every model due to cost constraints. Instead locate parts that have the same or similar functionality at a much lower cost to help save money on the overall cost of this project. Lastly, we recommend staying in contact with the producers of any acquired parts, as they can be very helpful resources during troubleshooting.

### Acknowledgment

We would like to thank everyone who has helped us through this semester, but there a few people we would like to extend a special “thank you” to. To our faculty advisor, Dr. Andrew Otieno, for providing the resources and information needed to complete our project. To our senior design instructor, Mr. Joseph Bittorf, for keeping us organized and giving us direction throughout the semester. Lastly, to Isaias Cervantes and Javier Sereno, for giving us the starting point of our project, making all that we have done possible.

### References

An Efficient Security Access System for Computers using Image Processing Techniques
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Abstract—This paper describes the method for an efficient face recognition system for access control to a computing device while utilizing image processing techniques. This unique method can be used for Windows, Linux, Unix operating systems. The proposed system detects the user’s face with a 98% probability and detects the intruder’s face with less than 1% probability. The detection time for the face is less than 2 seconds and unlocks the system within 2 seconds because of triggering all the tasks from windows, but still making it efficient from the previous works made. Additionally, the system application alerts the user when an intruder tries to unlock the system and also sends the image of the intruder’s face to the user, thus assuring maximum security to the system.

I. INTRODUCTION

Recently, there has been significant interest in the development of facial recognition due to its use in biometric technology which provides good security to any access. This has been very reliable since this method uses distinguished facial features to identify a person hence offering a quick, automatic, seamless verification experience.

<table>
<thead>
<tr>
<th>Graphics Card</th>
<th>Training and Testing Time</th>
<th>RAM</th>
<th>Detection + Unlocking Time</th>
</tr>
</thead>
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<tr>
<td>2 GB**</td>
<td>40 sec</td>
<td>4 GB**</td>
<td>9+9</td>
</tr>
<tr>
<td>6 GB*</td>
<td>20 sec</td>
<td>8 GB*</td>
<td>4+4</td>
</tr>
<tr>
<td>12 GB*</td>
<td>10 sec</td>
<td>16 GB*</td>
<td>2+2</td>
</tr>
</tbody>
</table>

Table 1. Different System Requirements and their results
Legend: ‘*’ are experimentally verified, ‘**’ are theoretically analyzed

In this paper, a deep neural network model is used to train and test the data. This system is created after studying various deep-learning models and other techniques for image segmentation and enhancement and analyzing their results against our model. This article purely describes only one efficient model and their results have been discussed. Also, this is integrated into the windows and Ubuntu operating system for ubiquity. The proposed system works well for Windows OS 8 and above, Ubuntu version 16 and above.

II. PROCESS

A. Input
A large number of face samples are captured using a haar cascade frontal face algorithm. In this case, 300 images are captured to cover all the possible facial features.

B. Image Segmentation
Firstly, it creates a boundary around the face to be detected using an object detection method. Instance segmentation is done to identify a single instance of the image, in our case a single face. Threshold segmentation sets a threshold value for the pixel values in the picture above which will be discarded for identifying the profile of a face. Mask R-CNN method is applied only for multiple objects so that it masks the background faces and captures only the frontal face [1].

C. Image Enhancement
The first stage in enhancing the image is to convert the RGB image to grayscale for conducting operations on it easily. Due to this conversion step, the background and the face may be blended or distorted, so it is necessary to do a face shape check. After this noise is removed from the image, sharpened and brightened.
D. Face Normalization

Face detection is a process of localizing and extracting the face region from the background. Those features are independent of face features and will affect the recognition rate significantly. The system of feature detection has detected three features such as left eyeball center, right eyeball center & mouth center. Each feature is detected using the Region of Interests (ROI) [2]. Then, Geometric normalization is applied to align the eyeball center and mouth center alignment. Lastly, brightness normalization is done by mean centering the pixel values and linearly smoothening the edges and normalizing the contrast with histogram equalization.

E. Feature Extraction

Feature extraction is the process by which certain features of interest within an image are detected and represented for further processing. Facial landmarks are used to localize and represent salient regions of the face detecting facial landmarks is a subset of the shape prediction problem.

![Fig 2. 68 Point facial landmark vector points](image)

The pre-trained facial landmark detector inside the dlib library is used to estimate the location 68(x,y) coordinates that map to the facial structures on the face [3]. Finally, 9/10th of the data is sent for training, 1/10th of the data is used for testing the data.

F. Feature Classification

Feature mapping is a pattern recognition technique used to categorize a huge number of data into a number of different classes. Firstly, the data is sent into the tensor flow and then into Keras which acts as a top layer to the system [4].

### II. RESULTS AND DISCUSSION

After the data is passed into the KERAS, we have got the value accuracy and value loss for the overall neural network and also loss and accuracy for the training and testing data in each epoch. It is clear if epochs are increased and the rate is decreased, there may be an increased accuracy, but dropout in neurons will be high, overfitting the system, so the system will not be efficient. Thereby increasing the probability of detecting the intruder’s face. The input shape for the MLP is 128 and activation functions used are relu and softmax and the Stochastic Gradient Descent(SGD) optimizer is used.

<table>
<thead>
<tr>
<th>No.of Epochs</th>
<th>Batch Size</th>
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<th>Loss</th>
<th>Accuracy</th>
<th>MLP Error</th>
<th>Probability</th>
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<tr>
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<td>0.38</td>
<td>0.62</td>
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</table>

Table 2. Results by changing different parameters.

### III. CONCLUSIONS

An efficient system for face recognition is created after studying various methods and analyzing them to increase the robustness and accuracy of the system. It is also integrated into the windows operating system without compromising the OS-user agreement by triggering tasks in the Windows task manager. Therefore, the system is very reliable and accurate with the results shown above. In the future, by increasing the number of facial points one can increase the accuracy of the system as more vector coordinates give many efficient results.

### IV. ACKNOWLEDGMENTS

The authors would like to thank Dr. Tahernezhadi and Dr. Azad from the department of electrical engineering for their technical and moral support throughout this project.

### VI. REFERENCES


Extinction Monitor Entrance Collimator
Mounting and Critical Lift

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Abstract- The Mu2e experiment could prove to be a monumental discovery for all of mankind due to the observation of muon to electron conversion. An extinction monitor is necessary to ensure that the proton beam fired is converted completely to muons. Since the proton beam has not been adequately mapped, adjustment and mounting of the entrance collimator component of the extinction monitor is required. Solidworks modeling, Ansys simulations, and hand calculations were completed to develop a design that could achieve this. Stresses and deflections were determined to ensure compliance with FESHM, ASME, and ANSI standards. An optimal design was selected, and the components of said design were deemed appropriate for the application.

I. INTRODUCTION

The grander scale of the senior design project is Mu2e itself. Negatively charged muons normally decay into neutrinos and electrons. However, there is an event that occurs once every one hundred quadrillion times, where a negatively charged muon will decay into only an electron. Mu2e’s purpose is to observe the pure muon to electron transition\cite{1}.

As shown in Figure 1, the main location of interest for purposes of this project is The Proton Beam Absorber. The beam will be fired in pulses in order for the Mu2e experiment to be executed successfully \cite{1}. As such, it is crucial to ensure that there are no remaining protons between each pulse. The Extinction Monitor provides a means to monitor the proton beam between pulses in order to ensure that proton extinction occurs. As the Extinction Monitor is tracking the proton beam, it is essential not only to have a means to lift the entrance collimator and hold it in place, but to be able to aim the EM at the beam. The proton beam’s exact location will not be able to be mapped until later in Mu2e’s project construction. As such, an adjustment of +/- 2” (51 mm) in all directions will be required.

The purpose of this project is to provide an engineering note containing a series of detailed drawings and analysis of the mount required for Fermilab to utilize for procurement and installation of the EM entrance collimator. A modified installation plan and requirements document have been completed in addition.

II. METHODOLOGY

For the critical lift and installation of the entrance collimator to be implemented effectively, a series of sub-systems were designed to allow for the minimal space and heavy load lifting requirements of the procedure. Figure 2 shows all of the subsystems working in unison to install the collimator in the nominal position. The final location entails the upstream flange being flush with the Extinction Monitor Magnet Room wall. The nominal angle is placed 9.7° below the horizontal plane. A series of cables and pulleys attached to an overhead hoist trolley system on the downstream end (a) will have the capability of vertical and horizontal adjustment. A
pivoting assembly on a rail (b) will secure the upstream lifting lugs of the entrance collimator with the upper portion of the assembly and will have enough degrees of freedom to allow for the downstream adjustment. The collimator will arrive on a holder subsystem (c) which allows for the collimator to be lifted in place by a forklift and shift the center of gravity over the forks. The forklift in question is a CGC70 with fork extensions and fork positioner [2]. The CGC70 is deemed to be safe for the application based on the load center of 42” (1067 mm) needing to be lifted 162” (4115 mm).

The collimator will have a weight of 5200 lbs (23.1 kN) prior to installation. After the nominal position and angle have been achieved, and the proper adjustment has been made, steel shot will be poured into an internal cavity in the collimator. The steel shot pour will increase the weight to 8200 lbs (36.5 kN) [3]. Further analysis will show that all subsystems will be sufficient for the critical lift according to Fermilab Environmental and Safety Hazards Manual (FESHM), ASME, and ANSI safety codes [4-8].

**Analyses such as the Ansys simulations shown in Figures 3 and 4 show that the proposed subsystems will accommodate the task due to the deflection being under 1mm(Figure 3) or the stress being under 92 MPa (Figure 4). Details on the analyses can be found in the final report. All components either have a manufacturer’s rating or have stresses found in analyses that are under the limits set by ASME, FESHM, and ANSI safety standards [4-8].**

**IV. CONCLUSION**

Overall, the design was proven to be acceptable for the desired task of critical lifting. All subsystems were accepted by a Fermilab design committee.

**ACKNOWLEDGEMENTS**

We would like to thank Nicholas Pohlman (PhD), Jifu Tan (PhD), Matthew Kleszynski (Teaching Assistant), Christine Ader (Mechanical Engineer), Dan Vrbos (Mechanical Engineer), and Peter Kasper (Senior Scientist) for their contributions is assisting with and critiquing the design.

**REFERENCES**

[5] ASME B30.16- Cranes and Vertical Hoists
Abstract -- The method of teleoperating a robotic arm is no small task. There are many questions that need to be answered, many problems that must be solved, and a vast amount of research that needs to be done for the system to work properly. This paper aims to solve the problem of how to teleoperate a 7 degree of freedom robotic arm with a haptic feedback device. There are many different types of information that go into operating this type of system. Inverse kinematics, forward kinematics, as well as the D-H Convention play key roles in the overall system design. The way that the haptic feedback device is connected to the robotic arm also plays a key role in the design and operational portion of this project. The Arduino Uno Wi-Fi Rev 2 is used to connect the haptic feedback device to the robotic arm. It also determines the different types of programming libraries that are available to be able to program the system. The operator must give a command by manipulating the haptic feedback controller in some way; at the same time the robotic arm must mirror the manipulation that the operator has given to the controller.

I. Introduction

Robotic arms are mechanically controlled devices designed to replicate the movement of a human arm. The devices are used for lifting heavy objects and carrying out tasks that require extreme environment and expert accuracy. The robotic arm most often is used for industrial and nonindustrial purposes.

There are many ways to control and operate a robotic arm. One way of controlling a robotic arm is through a teleoperation system. Teleoperation is the means of operating a robot by using human intelligence. It also requires a human-machine interface that is adequate for the specified tasks. The design for a teleoperated robotic arm controlled by a haptic feedback device is admirable because the robotic arm could be remotely operated, while still maintaining the same orientation as well as mirroring the motion given by the controller. One aspect of the robotic arm for the project is that it has 7 degrees of freedom.

Virtual environment display is done by sending the data obtained from the sensors to a computing device that creates a virtual environment based on the data from the first sensor. The computing device repeats the process for each of the sensors that are being used. Moreover, it includes a processor that is being used and some type of data storage. The 7 degree of freedom robotic arm is using a microcontroller to connect and operate the controller and the robotic arm.

The teleoperation system can consist of at least two robot manipulators [1]. These two manipulators must be connected in such a way that allows a human operator to control one of the manipulators. The manipulator that is controlled by the human operator is also known as the master arm. The master arm is the manipulator that generates the commands that are given to the remote manipulator, also called the slave arm [1].

There are a multitude of ways that the controller could be set up to control a robotic arm. One of those setups is by using a device that has haptic feedback. Haptics is a term that describes some type of touch feedback that is given to the human operating the haptic device. Force feedback as well as tactile feedback are the two types of haptic feedback that is given to the operator of devices that are equipped with haptics [2].

II. Design Description

Fig. 1. The Design of the Robotic Arm.

The Current design is made in such a way that it gives more advantages in several different criteria. First, it conceals all the electrical wires so when holding or moving the robotic arm position the wires will be untouched and it will prevent electric shock or disconnecting any wires from the motors. The design of the robotic arm provides a better mechanism while conducting any experiment. It also provides better torque and force since the design has no obstacle in between while conducting any experiment. Using DYNAMIXEL MX-28T servo motors it supports up to 360 degrees of precise positioning, and a wider control can be achieved with the newly contactless absolute encoder. It also has precise angular development over an entire 360 degrees of Position Control exclusive of a dead zone [4]. A rugged Metal frame design and 14 cm diameter ball bearing rotational base ensure maximum rigidity and accuracy. It shows the capability of the robotic arm to function at a certain orientation. The brackets are designed in such a way that it can handle any kind of pressure as well as heat. These brackets have some holes in it, it is
because of the motor releasing heat when it works so, these create an opening for the heat to go out and let the motor cool down. The major feature difference in its design can be seen on its shoulder, as it can support in such a way that its shoulder can support the gripper (the end-effector) to carry heavy objects and balance them while carrying out an operation.

Figure 2. The Touch™ Haptic Device [3].

Figure 2 is the Touch™ Haptic device. The Touch haptic device provides force feedback and it also enables to freely sculpt 3D clay, enhance scientific or medical simulation and easily maneuver mechanical components to produce higher quality designs. The purpose of using the haptic device is that it is used as a mechanized device that applies force feedback on the operator’s hand, enabling it to feel virtual objects and creating consistent with life contact sensations as the operator controls on-screen 3D objects. It can be used in diverse applications, including: Simulation, Training, Skills Assessment, Rehearsal, Virtual Assembly, Robotic Control, Collision Detection, Machine Interface Design, Rehabilitation, Mapping and dozens of other applications. It also has 6-degrees-of-freedom positional sensing and a 3-degrees-of-freedom force feedback [3].

III. Result and Discussion

<table>
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<th>Link</th>
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<th>D (mm)</th>
<th>A (mm)</th>
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</tr>
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<td>0</td>
<td>0</td>
</tr>
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<td>7</td>
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<td>129.6</td>
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<td>90</td>
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</tbody>
</table>

Table 1: DH Parameters for the Robotic Arm.

\[
T^0_7 = \begin{bmatrix} 0.5245 & 0.5328 & 0.6641 & -175.9480 \\ -0.7745 & 0.6225 & 0.1123 & 79.7265 \\ -0.3536 & 0.7392 & 0.2744 & 32.7494 \end{bmatrix}
\]

\[
R^0_7 = \begin{bmatrix} 0.5245 & 0.3228 & 0.6641 \\ -0.7745 & 0.6225 & 0.1123 \\ -0.3536 & -0.7392 & 0.2744 \end{bmatrix}
\]

\[
Q^0_7 = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \cdot 10^{-6}
\]

Table 1 shows the DH parameters for the robotic arm. Note that * represents the joint variable and those variables can change anytime if the robotic arm moves. The \( T^0_7 \) is Transformation matrix of the robotic arm which was calculated by using the principle of kinematic decoupling of Inverse Kinematics. The position and Orientation of the robotic arm could be considered independently. From the Transformation matrix, it is easier to find the Rotational matrix (\( R^0_7 \)) and Orientation matrix (\( Q^0_7 \)). The \( Q^0_7 \) is the Wrist Center of the Robotic arm and this could be calculated by using the equation shown above. The Jacobian matrix was used to determine the analysis and control motion of the Robotic arm. This helps in the planning and execution of smooth trajectories, in the determination of singular configuration, in the execution of coordinated anthropomorphic motion, in the derivation of the dynamic equations of motion, and in the transformation of forces and torques from the end-effector to the manipulator’s joints. All the calculation was done using MATLAB Simulation [5].

IV. Conclusion

This paper presented the proposal of a teleoperation technique, which is highlighted by the Touch™ haptic device to control a 7-degree-of-freedom robotic arm cohesive with a vision tracking system. The system utilized in this project is advanced in such a way that each mechanism corresponds with each other to give a unite feedback to get a better result. The haptic device empowers a bilateral manipulator of the teleoperation system. The objective of this project is to construct a model of an operational master-slave robotic system. For the improvement, a unique sort of servo motor is used called DYNAMIXEL and haptic feedback likewise a raspberry pie 4 model B desktop kit will be utilized to an interface device for the arm. Once everything is done, the developed robotic arm will at that point be mounted on a portable base, which was developed by previously, to perform even more testing undertakings.

Acknowledgement

The authors would like to acknowledge the support received from Dr. Ryu, and Witenberg Santiago with the Department of Mechanical Engineering at Northern Illinois University.

References


Abstract— Internet of Things (IoT) is a growing industry that is emerging to connect wireless protocols such as sensors, gadgets, and Bluetooth technology into an all-inclusive infrastructure network. Billions of devices will be connected that require some form of small, wireless power source, usually a battery. Within the IoT infrastructure inside an aircraft are remote sensors, often in inaccessible, isolated locations around the physical structure. Technological advances have hit a point where the efficiency and power consumption statistics are favorable allowing energy harvesting techniques to be used to provide constant charging to a battery. Both academic and industrial stakeholders are aiming to develop state-of-the-art technological design solutions by evolving existing energy harvesting technology to a point where the potential output exceeds the power demands of the system and negates the function of using a battery as an energy storage device. This paper outlines the specifications for harvesting unexploited energy sources such as vibrational kinetic energy at the resonant frequencies from an aircraft’s engines.

Keywords-component; Internet of Things; IoT; energy harvesting; vibration; magnetic induction

I. INTRODUCTION

A. Internet of Things (IoT)

The IoT is used to perform data acquisition activities, exchanging information and data within internet enabled systems. It entails a wirelessly interconnected network of physical devices exchanging data to facilitate enhanced ease of living [1]. Much of the IoT network is powered by batteries which exist as a finite resource and limits the practicality of such devices.

B. Wireless Protocols

Wireless infrastructure systems are becoming commonplace in applications requiring condition-based monitoring (CBM) replacing traditional, existing wired infrastructure. Application placement can be facilitated in previously inaccessible locations allowing the innovation of remote systems within an existing infrastructure network.

C. Magnetic Induction

Magnetic induction can be used to efficiently generate power using a combination of permanent magnets and enamel-plated motor wire. In accordance to Faraday’s Law of Induction, a potential difference is induced when an electrical conductor is passed through a magnetic field. The characteristics of a magnetic generator are determined by the properties of the electrical coil surrounding the oscillating magnet(s). Properties and geometry of the coil dictate the voltage output and the amount of power development by the system. [2].

II. DESIGN FEATURES AND MECHANISMS

![Assembled Device Model & Part Inventory](image)

A. Materials

1) Delrin

The design of the energy harvester warranted a low-friction, high-wear material. To achieve this, the engineering thermoplastic Polyoxymethylene POM (brand name of Delrin from Dupont plastics) was selected as the inner housing to contain the oscillating magnets in Figure 1.

2) Polycarbonate

The outer housing as seen in Figure 1 is constructed from the thermoplastic polymer polycarbonate which exhibits excellent manufacturing properties (molding, forming) while still possessing the necessary mechanical strength to hold the device together.
B. Neodymium Permanent Magnets

Neodymium-iron-boron magnets are widely used in the fabrication of permanent rare earth magnet applications. Given the high magnetic field intensity, producing push-pull forces, they can be used in a kinetic energy harvesting device along with an enamel-plated coil of motor wire to generate a usable voltage. This produced voltage can be used in conjunction with an existing battery to power a subsystem within the infrastructure network.

C. Resonance and Vibration

All mechanical mechanisms produce vibrations due to design or deficiencies within the system. Available energy sources are present in the surrounding environment which can be harnessed and transformed into practical electrical power. These mechanical vibration frequencies assuming proper inductance of the coil will also determine the frequency of the circuit. This property conjoins the mechanical and electrical properties of the device and ensures proper conversion.

D. Faraday’s Law of Induction

The electrical and magnetic portions of this device are key to its operation.

\[
V = -N \cdot \frac{\Delta(B \cdot A)}{\Delta t} \quad \text{(Eq. 1)}
\]

Faraday’s Law of Induction (Eq. 1) is the deciding law of science that drives this device’s operation. This ensures that when the magnets oscillate within the confines of the coiled wire, there will be an induced electromotive force (EMF, also known as Voltage) across the coil. If the equation is to be holistically examined in detail, then it can be observed that the Voltage will increase along with how fast the magnetic field changes within a certain time frame. Therefore, frequency of oscillation, number of coils turns, and magnetic field strength across the area of the coil will determine the voltage induced in the coil.

III. CONCLUSIONS AND OPTIMIZATION

This device provides proof-of-concept for harvesting otherwise wasted vibration. The iteration of design ideas has led to an operational, functioning prototype exhibiting a change in voltage when the device is placed on a vibrating surface under testing conditions.

The next phase of the project is to optimize the power harvested. Unfortunately, due to the outbreak of COVID-19 during the testing phase of this project, the device is not properly optimized for stable power rectification. Furthermore, lacking access to a lab meant that the group was unable to produce the proper AC-to-DC power converter and implement it on a PCB within the device.

ACKNOWLEDGMENT

The authors would like to acknowledge the assistance from Astronics Director of Electrical Engineering, Stephen Lingle and Project Engineer Addison Merchut as well as faculty support from Dr. Nicholas Pohlman, Associate Professor of Mechanical Engineering and Dr. Mohammad Moghimi, Assistant Professor of Electrical Engineering.

REFERENCES

System to Assist Elderly to Enhance Their Independence

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Abstract—As the number of elderly people choosing to stay at home increases, there is also an increase of different monitoring systems to help with the security of our loved ones. The monitoring systems in the market are expensive and contain recording devices, which can cause the person to feel they do not have privacy in their own home. A non-invasive monitoring system without any recording devices was created to be placed on the house of an elderly person who wishes to age in place. The system will be connected to an Android app that has two main features. The first feature allows authorized personnel to have access to live feed data which shows the location of the person in the house and the details of each sensor, while the second will send notifications in case of an emergency.

I. INTRODUCTION

“Aging in place” is defined as a person preferring to stay at their home as they age. As we age, the idea of giving up our independence and moving to another home or facility can come with both emotional and physical stress. This leads to nearly 90 percent of people over the age of 65 to say they prefer to live out their remaining years in their own home [1]. However, aging at home comes with many disadvantages. As people grow older their physical and mental health declines, which encourages families to send their loved ones to an assisted living facility or nursing home. Such facilities come with high monthly costs ranging from roughly $4000-$8000 [2]. This system demonstrates a low-cost alternative to monitor a person at home while ensuring their privacy. Older adults represent a vulnerable group as staying at home may turn out to be challenging when care needs to increase, particularly towards the end of their life.

Project Statement

The monitoring system will use the Internet of things (IoT) framework while using Google Firebase cloud resources to assist the elderly in their own homes despite their challenging physical and mental needs. The system will use several sensors to collect real-time data and identify various house activities by the elderly resident. Authorized users will be able to monitor the safety of a person living alone.

II. MATERIALS

A. PIR Sensors

The PIR motion sensors (Fig 1) will be used to monitor both the location of the person as well the time spent inside a room or outside the house. The PIR sensors will be placed on the entrance of the house and the entrance of every room. The sensors used for the system did not require extra components as they were only connected to an output, power source of 5 volts, and ground.

B. Temperature Sensor

The temperature sensor (Fig 2) will be placed in different locations of the house to monitor temperature changes in the house in case of a fire, or extreme low temperatures. The temperature sensor used in the system is the DS18B20 sensor. A 4.7k ohm resistor was connected between the 3.3 volts power supply and the GPIO 4 output.

C. Pressure Sensor

The pressure sensor (Fig 3) will be placed on the living room couch in order to help monitor the elderly person’s health. The Force Sensing Resistor (FRS) was used to measure the pressure created by sitting on the couch. A 10k ohm resistor was connected between the ground and the output pin of the sensor. The sensor was also connected to the 3.3 volts power source.

III. INTEGRATION OF THE SYSTEM

A. Hardware Integration

The design of the monitoring system (Fig 4) will connect the PIR motion sensors, temperature sensors, and pressure sensors to the Android app.
sensor to a Raspberry Pi. The Raspberry Pi will be used as the primary power source for the system to avoid battery use. The Raspberry Pi is also used to send the signals from the sensors to Google’s Firebase cloud services.

![Fig. 4. System Flowchart](image)

Google’s Firebase is the intermediate process for monitoring and displaying the different sensor readings in the app. It works as a handler for connecting real-time data of the embedded sensors, collaborates with a cross-platform application, and most importantly stores the data online in the Firebase database, known commonly as the Internet Cloud. The sensor readings are stored by using the URL of database which actually acts as a backend point. This unique URL of the database further helps the app to synchronize with the database.

**B. App Integration**

Data from the sensors will be updated in real-time in Firebase, which can be viewed in detail by using an Android App named “Enhance Living Alone.” The app will display details of all the sensors as well as the resident’s current location and will allow the user to set custom timers for warning and emergency notifications (Fig. 5).

![Fig 5. App](image)

**IV. RESULTS**

Through the integration of the system, it was possible to send real-time data from the sensors to the Google Firebase database. With the information in the database, authorized users are able to follow the elderly resident’s activities around the house. With the use of the app, the users are able to receive different notifications to warn them about unusual activity in the resident’s home.

**V. TESTING**

The system was placed and tested in a 3’ x 2’ one-bedroom model house. In a real-world situation the resident being monitored would be spending minutes to hours in specific rooms before it is deemed dangerous by the app, but for demonstration purposes the app was tested with warning notifications being sent after only 10-40 seconds. Temperatures were raised and lowered to extremes by using body heat and ice. By following the same layout and replicating the code with modifications, the system can be placed in a bigger house with more rooms and more sitting places or even smaller homes.

**VI. CONCLUSION**

Using the three different types of sensors, we were able to create a monitoring system without any video or audio recording devices. With the PIR sensors and the FRS we were able to know the location of the resident around the house, while with the DS18B20 temperature sensor, we were able to monitor safety by ensuring the house has a safe temperature for the resident to live comfortably, otherwise notifying authorized users in case of an issue. With this system, the safety of an older adult wishing to stay in their home can be assured without taking away the resident’s privacy. In the future this system can also be used for people with disabilities or health problems who wish to stay at home and enjoy their privacy.

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**REFERENCES**


GSM Enabled Sump Pump Failure Warning System

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Abstract—The Sump Pump Failure Warning System is a GSM enabled IoT system that can communicate with its user anywhere in the world. It can inform the user of rising or falling water levels, monitor multiple locations within a property for power failures, diagnose pump switch failures, and keep track of warranty information regarding the pump itself. Moreover, it features broad coverage audio warning options and its battery backup system allows for automatic and permanent battery maintenance and several days of independent operation. Simplicity of use and a minimum of maintenance were core concepts of this design.

I. INTRODUCTION

Unfortunately, severe weather events tend to be when a sump pump is needed most but are also when a sump pump is most likely to lose power due to outages. Even if a generator backup is available, the homeowner must be aware of the failure in order to act. Although it may seem like this is an unlikely event, storm damage and storm related flooding costs the United States $54 billion annually [1]. This fact is the motivation for this device, something that can allow the user to monitor their sump system remotely and will continue to function if the power to the house is lost. With a system like this, if power is lost or pumps are running abnormally, the homeowner will know about it no matter where they are. This is extremely important considering virtually no standard homeowners insurance plans cover damage caused by sump pump failures [2].

II. METHODS AND MATERIALS

A. Overall System Design

This package contains two classes of devices referred to as modules, which interpret data, and sensors, which collect data. A module called the Sensor Module will be strapped to the evacuation pipe on the sump pump and collect data from sensors installed on the pump system. There are two external sensors, a water sensor for monitoring water levels in the pit, and a current sensor responsible for monitoring the current draw of the pump and checking for abnormal behavior. If either sensor detects something suspicious it will radio a second remote module called the Communications Module. This device handles cellular communications between the user and the Sensor Module. It will receive threat information from the Sensor Module and contact the user via the GSM network. Both modules carry audio warning systems for added coverage plus have onboard voltage sensors that monitor the home’s electrical supply for any outages.

B. Water Sensor and Support Circuity

The water sensor is a simple pair of conductor terminals set a fixed distance apart. This will create a roughly fixed resistance when the terminals are submerged in water and allows the water to act as one resistor in a voltage divider together with a resistor on the Sensor Module circuit board. The node between these resistances is the input to an inverter which supplies zero volts to the MCU Digital I/O when water is not present, and five volts to the MCU Digital I/O when water is present.

C. Current Sensor and Support Circuity

In order to monitor the operation of the pump, an adapter was created that can split the power wires feeding the pump and measure the current draw over time. The power wire
acts as the primary single-turn coil of a transformer inside a SCT-013-000 current clamp. The analog signal induced on the second winding is dropped across a burden resistor, then rectified and smoothed from a sixty hertz sine wave into a five volt digital signal.

D. Sensor Module

The Sensor Module (SM) is based around the Atmega 328p microcontroller. It is powered by four 1.2V nickel-metal hydride AA batteries that are maintained by an LM317 based float charging circuit. This system was chosen due to its simplicity and resilience to overcharging. The sensor support circuitry is also located on the SM. Additionally, the SM carries an nRF24L01 Bluetooth antenna responsible for communicating with the Communications Module. It also carries a buzzer for audio warnings and an internal voltage sensor for detecting power failures on the circuit it is plugged in to.

E. Communications Module

The final major component of this system is the Communications Module (CM). This board carries the same MCU, Bluetooth antenna, buzzer, and power system as the SM. The primary difference is that in place of the sensor support circuitry there is a SIM800 based 2G GSM chip for cellular communications. This device receives radio data from the SM describing the state of the sensors via Bluetooth. Then, when a threat state is detected, it sends a text message warning to the user’s phone. Additionally, all information sent from the user to the device will be handled by the MCU on the CM.

III. DISCUSSION AND RESULTS

After the prototype was complete, four primary phases of testing took place. Phase one consisted of over twenty-six hours of testing and saw a 95% success rate. Software improvements were made and over the subsequent three testing phases totaling over one hundred hours, and one thousand simulated detections, not one failure occurred.

IV. CONCLUSIONS

This system is reliable and most importantly it fills a need that many people experience. Further, development costs indicate that if this product were to be brought to market it could sell at a very reasonable price.

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REFERENCES


Abstract - The growing scarcity of water around the world, especially in lesser developed countries (LDCs) with arid climates, has led to challenges in obtaining clean water for drinking and sanitation purposes. In these areas, many use cumbersome means to collect water which often take long periods of time. Additionally, proper sanitation is often not an option, thus leading to disease and illness. With a proper enclosure, the portable bladder well serves as a self-sufficient system for collecting and storing water underground until desired for distribution while also implementing a filtration system to ensure its cleanliness. Not only is water collection increased and automated, but concerns of illness and disease are reduced. Commercial implementation of such a device would revolutionize water storage and sanitization, along with solving a critical issue worldwide.

I. Introduction
Clean water and proper sanitation are essential for the survival and development of human beings. As of 2019, 780 million people do not have access to a reliable, consistent water source and 2.5 billion people lack access to improved sanitation [1]. The limitations of current water collection and sanitation technologies create a clear and definite issue worldwide, especially in LDCs with arid climates that have extremely restricted access to these technologies.

Capturing and storing water in LDCs is still a primarily manual labor task, while sanitation is often not ever considered. The water is stored in above ground tanks that are prone to collecting bugs and bacteria, which lead to disease and illness. The greater amount of water collected and properly sanitized, the greater these areas can thrive in health, which is linked to economic growth due to the averted healthcare costs and time saved [2].

To address these concerns, a system is designed that incorporates a collection system, water bladder for storage and accompanying filtration system. The water bladder, pictured in Figure 1, allows water to be easily stored and collected, while also being extremely portable. The bladder is made of elastomeric polyethylene, ensuring both flexibility and durability. As water enters the bladder, it expands until it reaches full capacity, and contracts as it exits without any concerns of stress. Additionally, the bladder consists of one inlet and one outlet for easy collection and distribution of water.

The water bladder itself was a component that was sourced from an existing product. The main structural designs for this project involved designing an appropriate casing to store the water bladder and all other system components underground, as well as a funnel to collect water. The casing consists of corrugated steel sheets that are secured to an assembled 6061 T-slotted aluminum framing. The funnel is attached to the top of the framing and is made of galvanized steel sheet metal. These serve to protect all system components from external factors such as animals and insects.

The assembly was modeled using SolidWorks as shown in Figure 2.

II. Materials and Methods
In addition to the structural components, a system was designed to provide filtration and distribution of the stored water. Components of this system were connected using Schedule 40 PVC piping. A section separated from the funnel and bladder by sheet metal serves as housing for the electrical components, which sanitize and move water throughout the system.

The control for the sanitizing system is comprised of single pole relays and single pole time delay relays. These timers continuously call the sanitizing cycle, purifying the water in the bladder with an Ultra-Violet light filter, which loops back into the bladder by powering a normally closed valve; this prevents bacteria growth. Level sensors use water in the bladder to close the circuit and check water levels. Ladder logic was created on a PLC programming software, CLICK, and checked for errors. The control panel system is build-to-test, to allow the panel to be wired in functional segments for test during build. The control panel is pictured in Figure 3.
A solar panel is used to power the system and charge the battery. This allows the system to be powered off grid and implemented in a large range of geographic locations. The voltage from this panel is in the form of DC and an adapter is used to invert this to AC for the pump and UV-filter. This setup is shown in Figure 4.

III. Results and Discussion

In order to verify the structural design, finite element analyses were conducted. The amount of pressure applied to the framing and funnel is due to the weight of the gravel, solar panel, and electrical panel. Both minimal deformation and equivalent stress are experienced on the device, with the pressure respectively applied to where it acts. See Figure 4 below for deformation results.

IV. Conclusion

Water collection and sanitation desperately needs new, efficient, adaptive technology for not only LDCs, but also globally. Portable water bladders stored underground offers an economic, healthy, and automated solution to existing sorting techniques. Structural devices, backed by sensors, filters, and prototyping experimentation allows for large-scale water collection and sanitization to occur. A bladder well device capable of collecting, storing, sanitizing, and distributing water has been designed and analyzed with partial construction and experimentation evaluated out of relatively similar materials. This lays the foundation for future adaptation of portable underground water storage systems through the curation of the project by proceeding teams or commercial implementation. A commercialized design would utilize a larger-scale device so that the amount of water collected and sanitized can serve an entire community.

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Design of a 3D Puzzle for Building a Robot

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Abstract— Creating a method for teaching robotics to younger students will be beneficial for individuals with interest in pursuing robotics. The students should be able to learn different aspects of robotics from the kit that would be provided. Through the assembly process, they will be able to learn by seeing how the linkages of the leg work together to create motion, and how the components should be fastened together. The electronic components should be able to teach these students about the wiring that is needed to connect all the components together as well as the programming needed to allow these components to work together to allow the walker to function correctly.

I. INTRODUCTION

As the need for automation increases in business, robotics become more and more common. As this need for robotics and automation increases, the importance of the younger generations getting an early introduction to robotics will increase as well. Providing an easier and more affordable way to teach students that show interest in robotics at a younger age will be able to provide a head start on their education.

The challenge is to create a robotics kit that will not be overly priced to manufacture or sell. The robot should be like a puzzle, where the user will get instructions, a workbook, and an unassembled robot that they will have to assemble themselves. The workbook will have the wiring schematics of the electrical components, as well as information and lessons on programming all the components to work together. The robot should be quick to assemble.

II. WALKER DESIGN

The robot that was designed was a walker design. This design required both a mechanical design aspect for the legs and base, and an electrical design for electronic components and the wiring schematics. Press fit binding posts are to be used for fastening all the components together to minimize the time for assembly.

Figure 1: Fully Assembled Model

Figure 2: Living Hinge Leg Design

A. Mechanical

To minimize the number of components needed to build the robot, the idea of incorporating living hinges in the design was considered. A living hinge is a thin flexible hinge that is made from the same material as the two pieces that it connects, these living hinges are used in many different products and require the material to be flexible enough to bend, but strong enough to not break or buckle under loading. For this reason, Polypropylene was chosen as the material that will be used in all components that would use hinges of any kind.

The walker design was created modeling its legs after the Klann Linkage design, one reason being that it had the smallest range of angles that each link would rotate through. The largest angle of rotation that would be replaced by a living hinge would be only 25 degrees. By changing some of these connections between links from pin joints to living hinges it would minimize the amount of components needed to construct the legs, and by creating the geometry of the hinge to be a certain shape and thickness, the hinge will allow more than the required angle of rotation.

To create the robot, a sturdy base would be needed, which would have a platform to mount the electronics, as well as two walls to mount legs on either side. Instead of having multiple pieces being fastened together to create this base, the idea was to create this out of one single flat sheet. With the idea of living hinges, a similar concept could be applied to allow a flat sheet to fold in certain locations by cutting a 90° v-cut across that section of the sheet where it should fold. With these folds, the material can be bent in a way that the two ends of the sheet will meet and two hook shaped cutouts could be inserted into the opposite side and create a locking mechanism to create a sturdy base structure for all the other components to be mounted onto.
Testing was done to determine the lifespan of the living hinges and the folds in the base. A fixture was designed and created where a motor would be mounted, and an arm would be attached to the motor. When power was sent to the motor, the arm rotated and pushed material of the living hinge. The hinge was then rotated by the arm and underwent over 10,000 cycles without failure.

Another form of testing that was planned, and unfortunately cancelled, was to have kits sent out to middle school age students to have them assemble the robot. They would have been timed and would have given feedback on how easy they thought it was. There would have been a survey with this data, and it would have given us insight on whether the main purpose of teaching students was successful.

B. Electrical

The goal was to design a robot that had the capability to avoid collisions. To do this an ultrasonic distance sensor was used to detect the distance between the robot and an obstacle. A motor driver was used to power the DC (Direct Current) motor and an Arduino Nano was used as the microcontroller. In addition to simply avoiding obstacles, a second control program and circuit was made that would allow for the study of the dynamics of the robot. It will still maintain all the components and functionality of the obstacle avoidance system; however, a 6-axis accelerometer will be added to study both the linear and rotational acceleration about each axis. This data, as well as data from the ultrasonic distance sensor will then be saved to an SD card so it can be imported into a computer program and studied.

III. MANUFACTURING

A. Waterjet

The leg links with living hinges were cut with a waterjet out of a 1/4-inch thick polypropylene sheet. This allows for multiple of these linkages to be cut out of a single sheet. The material at the location of the living hinge was very thin measuring at 0.05” thick. This manufacturing process was utilized due to the thin material condition and the complex geometry that was required for the living hinge.

The outline of the base was cut out of a 1/8-inch thick polypropylene sheet using the waterjet. The hole locations where the electronics case and the legs were mounted were also cut out with the waterjet in the same operation.

B. Mill

The 90° V-cut grooves that were cut into the Polypropylene base were cut using a 90° drill bit. The material at the center of the V-cut had thin material conditions measuring at 0.05” thick to allow for bending and folding of the material.

C. 3D Printing

The components for the housing that hold all the electrical components and the motor were 3D printed, due to complex geometries. This cuts down on manufacturing time and material waste. Extensions for the drive shaft of the motor were also 3D printed for ease of manufacturing.

D. Laser Cutting

All links for the leg design that did not incorporate living hinges were laser cut out of a 1/8-inch thick acrylic sheet. This allowed multiple links to be cut out of one sheet in a short amount of time.

IV. YOUTH STEM EDUCATION

This robot can also serve as a great teaching tool to get young students interested in STEM, by allowing them to get hands on and assemble a walking robot. Students would be given the components needed to build the robot, along with instructions on how to fold the body into shape and lock it into place. As well as how to mount the legs and the electronic housing to the body.

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REFERENCES


Robotic Mobility Walker for those afflicted with movement disorders

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Abstract—The focus of the design is creating a high functionality, low weight, and low maintenance walker that would increase the freedom of movement of the user. In this case, the main goal of the Robotic Mobility Walker’s design is to help improve the quality of life of a high school student with Dystonic Cerebral Palsy (DCP). With that in mind, various aspects of the walker were tailored to help meet their needs. Namely, a design that would be compact enough to move through small doorways and aisles between desks, help assist in sitting and standing, and help avoid any unseen obstacles or dangers. These features help not only the student but anyone who has trouble moving unassisted.

I. INTRODUCTION

Dystonic Cerebral Palsy, or DCP, is a movement disorder in which involuntary muscle contractions cause the twisting and stiffening of various muscle groups. These unintended muscle contractions can affect any muscle group anywhere on the body, leading to a lack of overall motor control. As a result, many of those afflicted with DCP develop a very inefficient gait or walk cycle that makes moving even a small distance an incredible challenge. In order to overcome this a mobility assistive device is used to either help correct the cycle or as a general aid to help them increase their mobility. These devices come in various forms ranging from crutches to wheelchairs depending on the severity of the disorder.

Fig. 1. Concept art (By Erin Crawford)

Crutches are used if the person afflicted has a relatively strong upper body stability and can support themselves. While a wheelchair is used when the person is unable to support themselves in a standing position. Neither device is perfect as each person has varying needs of degrees of body support. When a person requires upper body support (more than what crutches provide) but is still able to independently move their legs a walker is used. A walker allows the user greater stability than what crutches provide. While at the same time the walker allows the user to exercise their legs to prevent muscle wasting and improve their walk cycle.

Walkers (and other mobility aids) tend to greatly increase the quality of life of those with DCP due to the increased freedom of travel they provide.

II. MECHANICAL DESIGN

A. Material

In order to fulfill the goal of keeping the walker lightweight and robust, Aluminum was chosen to be the primary material of the frame. Aluminum has a high strength to weight ratio and is corrosion resistant. The covers for electrical and components will be made of 3D printed PLA plastic. The PLA is rigid, and due to the shell’s thickness, water-resistant.

B. Frame/Linkage

The top chassis of the walker consists of a U-shaped structure that acts as mounting points for a single scissor linkage, user input medium, and physical support for the user. Connected to the U-shaped structure is a single scissor linkage on either side comprised of two long tubes that are connected at the center with a pivot joint forming an X shape. This single scissor linkage is collapsible, offers a broad range of height, and uses a minimal amount of materials. Using this linkage results in a walker that stows easily, is highly adjustable, and lightweight. The bottom of the walker’s chassis consists of a similar structure as the top. Linear actuators are located on either side of the structure to provide vertical actuation to the scissor linkage. Attached to this structure are 4 wheels, with the rear wheels being attached to casters and front wheels that are driven by Mini CIM motors. A support member connects the two front wheels serving as a mounting point for electrical hardware and as a bumper.

Fig. 2. Example of single scissor linkage
All permanent connections on the frame the aluminum tubes are welded together using the AC TIG process. For the pivot connection at the center of the linkage, a shoulder screw is used allowing the linkage to move freely. Any joints that require less than 360-degree non-continuous motion use Oil-lite bushings. For high load, low rotation joints, bushings are better than bearings as they have less axial play, require no maintenance, and are lighter and cheaper [1].

III. ELECTRICAL DESIGN

A. Power System

The walker in its current iteration is being powered using four 20V DeWalt MAX 8Ah batteries in parallel. These batteries were selected due to them being readily available at any hardware store, high durability, and high energy density. They are connected to the main power rail using a specialized adapter. As 20V is higher than what most electronics and motors can take, the voltage is stepped down using a 20V to 12V DC switching buck converter. This 12V is then fed into the walker’s two brushed Mini CIM motors and the walker’s main electrical components.

B. Control Systems and Sensors

At the center of the walker’s electronic is an Arduino MEGA 2560 Rev3. The mega runs the main code needed for all walker operations including battery monitoring, tilt and proximity detection, and the motor control functions. The walker is controlled through two industrial joysticks, provided by last year’s team, in a “tank drive” control scheme. If the user lets go of either joystick at any time the walker halts movement until the joysticks are held again. Using GY-521 breakout board for a MPU-6050, the mega checks the walker’s tilt relative to the horizon. If the walker at any point exceeds a preset angle, a warning is displayed on the walker’s SSH1106 OLED and alerts the user using piezoelectric speakers. A similar warning is used if the user comes to close to a ledge using the SHARP GP2Y0A21YK0F IR distance sensor. The OLED also displays the remaining battery life for each battery using a MAX17261 fuel gauge IC located in the base of each battery adapter.

IV. CONCLUSION

The Robotic Mobility Walker increases the freedom of movement for those affected by DCP or other movement disorders using creative and efficient design. The compact mechanical design allows the walker to be easily stored and transported, as well as minimizing any pinch points. The electrical design aids the user with various information about their surroundings and assists the user’s movement over most terrain. The walker will dramatically increase the quality of life for those that are mobility impaired.

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REFERENCES

**Smart Hand Tool Technology**

**HAVSafe**

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**ABSTRACT**—The purpose of HAVSafe is to combat Hand-Arm Vibration Syndrome (HAVS); a disorder that results from prolonged exposure to vibration, specifically to the hands and forearms while using vibrating tools. Symptoms range from tingling, numbness, pain, blanching in the fingers, weakened grip due to nerve and blood vessel damage and in severe cases gangrene can occur. About 2 million U.S. workers are exposed to hand-arm vibration, and as many as half will develop HAVS [1]. It can take as little as six months to six years to develop and, after the fingers blanch, the condition is irreversible making prevention crucial. HAVSafe is a compact device that is fastened to the handle of a power tool, close to the operator’s hand, measuring vibration exposure and notifying the user when unsafe levels have been reached.

**Keywords:** Hand-Arm Vibration Syndrome, exposure limit value, weighted acceleration, accelerometer, durability

I. **INTRODUCTION**

Hand-Arm Vibration Syndrome has a high prevalence among workers who are in industries that heavily rely on power tools such as metal-working trades, automobile assembly, foundry work, forestry, mining, and construction [2]. The effects these workers feel is a combination of the frequency of the vibration (lower frequencies are more harmful than higher) the climate in which work is done (colder temperatures are more detrimental to warmer ones as the cold reduces blood circulation) and the amount of time spent using the tools. A popular preventative measure includes the use of anti-vibration gloves, which, the user will receive little benefit from for frequencies under 25 hertz [1]. They are mostly effective in holding a tool in place, keeping the hands warm and protecting against cuts and abrasions. HAVSafe is a more reliable alternative as an accelerometer is used to measure the vibration intake in all three orthogonal directions. A microcontroller is imbedded to take data from the accelerometer and displays the output through a light emitting diode. The diagram below shows the flow of internal components.

![Diagram](image)

**Figure 1. Process in Collecting Data**

Most standalone microcontrollers only come built with enough memory for a few small programs to be executed. In order to store the amount of data that would be gathered in over eight hours, a much larger data storage medium would be required. HAVSafe stores the data into a microSD card. The information collected can also be manually transferred to a computer via microSD card for further data analysis and logging.

II. **EXPOSURE**

The greater the exposure level, the greater the risk and the more action employers will need to take to reduce risk. For hand-arm vibration the exposure limit value (ELV) on any single day is 5 m/s^2, the exposure action value (EAV) being 2 m/s^2 over an eight hour period [3]. The image in Figure 2 shows the conditions in which HAVSafe will display certain colors to the user. If the value calculated is below the EAV the device will continue to display green, if and when the value falls between the ELV and the EAV it will emit yellow to warn the user, and when above the ELV the light will flash red telling the user to stop immediately. It is important to note that these values are raw acceleration while HAVSafe uses weighted acceleration values.

![Graph](image)

**Figure 2. Exposure Duration v. Vibration Magnitude**

III. **OUTER CASING**

HAVSafe is rectangular in shape, the symmetry makes distributed loading on the device simple and does not interfere with the user. As the industrial workplace is a harsh environment, it is likely the tools along with the HAVSafe will be dropped and experience unkind natural elements. To protect the components inside the device the outer casing is made with 6061 aluminum alloy T-6 due for its durability, weather resistance and low thermal expansion rate. Externally the device is wireless, the user can eject the microSD card to examine the data collected, plug into a USB port, and press a switch to turn the device on and off.

![Image](image)

**Figure 3. Casing**
IV. Printed Circuit Board

The printed circuit board embodies a 1.25 inch by 1.737-inch dimension and is 0.12 inches thick. An accelerometer that can withstand great force and with an appropriate bandwidth is placed in the middle of the board. To make the board as small and compact as possible, the microSD card was placed on the underside of the board. The battery lays behind the board and has a small connect making it easy to replace the battery by simply opening the case and unplugging the battery from the top of the board. A silicon damping material is placed inside and around the board to absorb shock to protect the components and most importantly the accelerometer.

A. To achieve consistent and correct acceleration readings, Clock Timer Interrupt logic was used to sample the continuous vibration signals being received from the accelerometer at regularly spaced time intervals. Signal noise is disregarded, and the resultant acceleration is then used to evaluate if unsafe levels of vibration have been experienced.

B. The System on Chip processor houses all the components of a computer on a single integrated circuit. The processor allows for the use of MbedOS, which includes a multithreading feature allowing HAVSafe to continuously read from the accelerometer in one loop and simultaneously process the data in a separate loop without sacrificing acceleration read speed with long data processing functions.

C. The push button allows for the users to interact with the device in order to start, stop, pause as well as reset the device. On reset, data is saved to a log file on the microSD card, then the current vibration monitoring session data is cleared and a new session is started.

D. Considering HAVSafe is to be used in high vibration environments, a hinged memory connector ensures a secure contact by locking down the card restricting any movement.

E. Power comes for a small lithium ion battery that operates for up to 12 hours and lasts 5 years.

V. Mounting Methods

Power tools in the work environment experience large amounts of vibrations, making it difficult to mount things in a secure manner. HAVSafe uses a nylon strap attached to the back of the device to fasten onto nearly any type of power tool regardless of the material on the handle. As double protection to keep the device from moving, small neodymium magnets are found on both sides of the nylon strap. They work best on a clean, flat surface that is made of magnetic material i.e. iron or steel. The strap can be unfastened to easily move the device from one tool to another. For extra security the user can also purchase an industrial adhesive to apply on the back of the device.

VI. Safety

According to the OSHA Standard 1910.303, only electrical voltages of 50V or more is considered unsafe for human contact. HAVSafe would never exceed a voltage of 5V and is therefore considered intrinsically safe for contact with the skin. The materials that make up the entirety of the device are commonly found in daily life and in industrial environments and do not contain radioactive materials or any material known to be hazardous to biological life.

Workers should also be informed of the risk of Hand-Arm Vibration Syndrome and how to protect themselves against it. Along with the use of HAVSafe, users should keep their hands warm, grip the tool lightly, keep the tool well-maintained, take breaks- a good rule of thumb is ten minutes per hour- and seek medical attention if symptoms appear.

Other devices have broken codes in ethics by withholding data from their customers, with HAVSafe, the user can access the precise data immediately. This device follows ISO 5349 standards for compliance and protection to guarantee it is mounted correctly and does not interfere with the user [4].

VII. Acknowledgements

This project required an enormous amount of research, time, and dedication for the many learning curves there were to overcome. It is the result of many that helped in assisting us in the creation of HAVSafe who we would like to extend our sincere gratitude. First and foremost, we would like to thank Dr. Donald Peterson in being the focal point in our project supporting us and passing his knowledge from the very beginning and supporting us every step of the way. Thank you to Justyna Kielar for taking the time to diligently critique our work and Simon Kudematsch for extending his knowledge and advice for the success of this project. Thank you to Mr. Miguel for all technical understanding and lending lab equipment. Thank you to all colleagues for their kind encouragement.

VIII. References


Abstract – The purpose of Stirling Silver is to repurpose wasted energy thermal energy in a house or building and regenerate it into electrical energy. This project primarily uses a Stirling engine, an alternator, and a furnace exhaust flue to achieve this goal. Most people have realized that energy consumption is a primary focus of concern and that efforts need to be made to both reduce current energy wastes as well as lower the overall demand for energy consumption. Stirling Silver is a unique and efficient way to meet those demands.

Keywords: Stirling Engine, Piston, Displacer, Lathe, Mill, Exhaust Flue

I. Introduction

Given the ever-increasing demand for renewable energy in today’s society, the desire for new and efficient renewable energy has become an engineering priority. Current renewable energy sources commonly used include solar, wind, geothermal, biomass, and hydropower. Combined, renewable energy accounts for around 13.5% of the world’s total energy supply. These energy sources primarily exist as large-scale systems. Contrarily, Operation Stirling Silver aims to create renewable energy on a smaller scale that can be utilized in nearly every building or home.

Operation Stirling Silver’s main device is a Stirling engine. Stirling engines are sealed engines that create rotation energy by converting translational energy created by a piston affected with changing temperatures and pressures. In comparison to the common internal combustion engine, Stirling engines use heat created outside their cylinders to provide the temperature changes necessary for thermal expansion. Stirling engines can be found in three different configurations: alpha, beta, gamma. Operation Stirling Silver specifically uses a beta configuration. This style uses a single cylinder with two pistons. One of the pistons acts as a displacer. This means it has a smaller diameter than the cylinder so as to displace the gas, air in this case, back and forth between the heated and cooled ends. The other piston is forced up by the changing pressures. Together, the two pistons work to turn a crankshaft which then is connected to an alternator to generate electricity.

What makes Operation Stirling Silver unique is that it is adapted to be powered by an ordinary furnace. The exhaust on a furnace is essentially wasted heat energy being expelled into the atmosphere. The temperature of this air can reach as high as 500 degrees Fahrenheit. As you can see this is a non-insignificant amount of energy being wasted that our Stirling engine can then convert back into mechanical energy to create usable electricity.
II. Materials and Methods

Operation Stirling Silver is primarily constructed of 6061 aluminum. Aluminum was chosen due to its properties as a strong, lightweight material that has good thermal conduction. These factors provide optimal conditions for a Stirling engine to operate. Aluminum also provides the added benefit of being readily available and reasonably priced in comparison to other metal building components.

- The production of the Operation Stirling Silver device requires multiple machines. Lathes, mills, saws, welders and other tools are used to build this device.
- The lathe is primarily used for ensuring that the piston, the displacer, and the cylinder housing are all properly shaped and sized.
- The saws are used for cutting all of the various shaft lengths needed for the piston and displacer as well as for the crankshaft.
- The mill is used for cutting and shaping the various sheet and block metals for housing, fins, and brackets.
- The welder is used to assemble any parts that can’t be affixed by screws or bolts.

III. Applications

Stirling engine devices have many applications. Operation Stirling Silver specifically is to be used to collect wasted heat from a furnace. However, the device is capable of operating given any reliable heating source. We have designed a housing to be placed on a furnace exhaust flue, but any heat can be applied. These could include, but are not limited to: A direct flame, induction heating, and radiated heat focused onto the device. Operation Stirling Silver can be used in many applications and can provide usable energy.

IV. Conclusion

This project is designed to increase thermal and electrical efficiency in homes and businesses. Energy needs have always been and always will be a vital and ever-growing aspect of society and the demands of the industry do not appear to be going down in the foreseeable future. We believe this project is an important step towards limiting our energy waste as a society. This Stirling engine application is unique in that it will be simplistic enough to be adapted to almost any high heat loss device but efficient enough to warrant the installation and long-term maintenance.

A thermal study was conducted as well as a real-world 3D printed prototype to provide proof of concept of the device.

V. Acknowledgments

We would like to thank Northern Illinois University for their continued support during this trying semester. We would also like to thank Dr. Peterson for organizing the class, as well as Dr. Ghazi Malkawi and German Ibarra for their ongoing assistance throughout the project.

VI. References

A Light and Portable Temperature Chamber for Testing Breadboards in Engineering Labs

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Abstract- It is important for engineers to be able to test circuits over wide temperature ranges. This device would allow engineering students to test circuit boards under a wide range of temperatures. Without unplugging or detaching any components of the circuit board itself, the student or individual will be able to set a desired temperature, view the actual temperature, and observe the effects. The portable, safe, and easily operable invention can greatly advance the knowledge to improve the results of circuitry building and understanding.

I. INTRODUCTION

The Northern Illinois University Laboratories need more ways engineers may expand their knowledge. When building circuits on breadboards, the electrical labs have no way to test them at a range of temperatures in order to see the effects on the circuit itself. Any other traditional compressor-based refrigeration unit would be too bulky and complicated for students to use in the lab. The environment’s operating temperature should not extend past 50-90 degrees Fahrenheit. This project is to design a Peltier based containment unit that can create an environment that cools and heats a range of 0-70 degrees inside chamber. The device would be beneficial in finding more ways to observe and improve on basic circuits being built by engineering students.

II. MATERIAL AND METHODS

The device shown in figure (1) was made of a box using acrylic sheet and connected using solvent cement. Eight Peltier devices were mounted on top. Each pair of Peltier were cascaded on top of each other and connected in series, and each two pairs connected in parallel. The pair of Peltier’s were sandwiched between aluminum heat sinks with thermal paste. Two fans were mounted on the top side of the box, one large fan mounted in the bottom side of the box, and one fan mounted on the back side of the box for the circuit board. A touch screen was mounted on the top front side of the box. A power supply was mounted on the back side of the device. The control circuitry and the raspberry Pi were mounted on top of the power supply on the back side of the box. A printed cover was placed on top of the wires and the back side of the box.

Figure (1): Temperature-controlled Chamber
Peltier’s have hot sides and cold sides depending on the direction of current flow. H bridges are used in order to reverse the current directions to heat or cool. Each H-bridge was made of five N-type MOSFET as shown in figure (2). The first MOSFET was placed on the beginning of each H-bridge to simply turn the system on or off. The other MOSFETs were used to make two paths for the current by turning one of the top sides and one of the opposite bottom side. To use the MOSFETs as switches a voltage applied to the gate terminal from a photo diode array that generates the voltage required to turn on the MOSFET. The photovoltaic driver generates a voltage by getting a small current from the Raspberry Pi to illuminate and internal LED to generate the light for the photodiodes to convert to voltage. A 1M ohm resistor was placed between the gate and source terminal of the MOSFETs to discharge the photodiodes when the LED is off. The device circuitry is shown in figure (2).

![Device Circuitry](image)

**Figure (2): The Device Circuitry**

**III. RESULTS AND DISCUSSION**

The circuit was tested using a multimeter to check for the voltage value in each direction. The temperature from the sensor was displayed on a user interface program. A user can set the required value and the output of Raspberry Pi was checked for each direction using a multimeter. The user interface program is displayed in figure (3). This work made an important step in developing a temperature-controlled chamber for lab circuits using inexpensive and commercially available materials.

![User Interface Program](image)

**Figure (3): User Interface Program**

**IV. CONCLUSION**

In conclusion, the project goal is to design and build a temperature-controlled chamber for breadboard circuits. The containment can be set to any temperature between 0 and 70 °C. The customer has asked that a Peltier device be the mode of temperature change. The Peltier is a much simpler, smaller, lighter heat pump than a traditional refrigerant compressor. Peltier’s make portability possible by reducing weight and size. The complete chamber includes handles attached to it so that the device may easily be placed over the breadboard. The LCD touchscreen makes it easy to set and monitor internal chamber temperatures.

**V. ACKNOWLEDGMENT**

The authors would like to thank Edward Miguel and the Department of Electrical engineering at Northern Illinois University for his technical assistance and guidance.
Device To Simulate Biomechanical Exposures Due to Power Tool Torquing

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Abstract—Workers in various industries experience exposures to impact due to the use of high-powered torquing tools. These exposures are associated with an array of Musculoskeletal Disorders (MSDs), particularly in the upper extremity. In order to allow researchers to study these effects as well as to evaluate currently emerging ergonomic interventions, a new research tool is needed. This document describes the design and construction of a novel device capable of simulating biomechanical exposures due to power tool torquing in a range of 1 to 4,000 Nm. This is accomplished by using a small DC motor to spin a weighted flywheel where, through a clutch mechanism, the torque is transferred to a handle held by the user. The design features easy setup, fast reset times, intuitive user interface, multiple safety features, and is made of durable materials. The entire project weighs less than 40 kg and costs less than 1,000 USD.

I. INTRODUCTION

In many industries around the world, power tools are used in factories to assist workers in applying torque to fasteners. Because of the high amount of force used on these fasteners, the tools used can cause Cumulative Trauma Disorder or CTD in the extremities of the user. This disease is the cause of many injuries each year, resulting in a loss of quality of life for workers, as well as a loss of productivity for companies in addition to liability. Previous research has been conducted on how these tools effect the human body, but in recent years a necessity for new research was created. Biomechanical exoskeletons are used to alleviate the forces on the human body, and research must be done on how long-term use of these exoskeletons may impact the user. This new research will help evaluate if there is any potential risk to the user or help find the benefits of these exoskeletons for even further implementation of biomechanical assist devices. In order to conduct this research, a device to simulate the torque motion of power tools needed to be created. Currently, no product has been widely produced for this purpose.

The objective of our device is to create a user definable torque motion that can be repeatedly applied to a handle and eventually a test subject. Using a small DC motor, a weighted flywheel, a standardized handle, and an array of various sensors and actuators, we were able to replicate the motion of various torque tools.

Figure 1. CAD model of the project.

II. MATERIALS AND METHODS

A. Requirements

The main design constraint encountered was a financial constraint of $1000. Another requirement needed to be met was being safe for lab use. This meant that the design needed to be mountable to T-Slotted 8020 Aluminum, as well as being safe for human testing. To ensure this, multiple emergency stops and other safety features, both software and hardware, were implemented. Because the device is used for human testing, safety is the most important requirement. For performance, the device had to meet the torque requirements of 1 Nm up to 4000 Nm. There were no requirements for the total weight of the project.

B. Prototype Design

This prototype consists of a combination of several custom-made parts as well as ready to order parts. The overall design was fabricated around the idea of a clutch system and simple motor and pulley system. The combination of these two systems as well as a custom braking system was developed to produce the final design.

1. Drive train

The drive train consists of a DC motor that spins a rotating mass which produces a torque once the braking mechanism has been applied. The motor and rotating mass (i.e. flywheel), are connected using a belt.

2. Hardware

The hardware of the system consists of an enclosure, mounting shaft, and handle. The enclosure is made of .00635m steel for the back plate and bottom plate. The rest of the enclosure is made from 0.00635m thick acrylic. The flywheel, brakes, and handle are mounted to a .0254m thick steel shaft that is mounted to the steel back plate. The handle is a certified aluminum handle that is in compliance with ISO-10819 used specifically biomechanical research.

3. Braking System

The first of two braking systems is a spring-loaded caliper that is controlled by a linear actuator. This caliper is used to force together two brake disks that transfer power between the flywheel and handle, similar to a clutch. The second braking system is used for safety precautions. The rotating flywheel has a mechanical brake caliper that is also controlled by a linear actuator. In the event of an emergency, this braking system will be used to make sure unwanted freely spinning mechanisms are coming to a halt.

4. Sensors and Actuators

This system requires an array of sensors and actuators including a Hall Effect RPM sensor, a resistive pressure sensor, linear actuators, voltage relays, resistive...
strain gauges, and PWM controllers. All of these were controlled using an Arduino Microcontroller (Arduino Mega 2650, Arduino, Sommerville, MA) and LabVIEW software (National Instruments, Austin, TX).

III. RESULTS

In order to maximize the efficiency of power transfer and reduce loss due to friction, the stopping time of our brake system was assumed to be instantaneous \( (t = 0.001 \text{ seconds}) \). Based off this assumption, we were able to calculate a simple linear relationship of the maximum torque created at different flywheel speeds. The inverse of this relation is used to take the desired torque from the user and convert it to the necessary RPM of the flywheel for each test.

![Expected Torque per RPM](image)

Figure 2. Expected Torque per RPM

In order to test the strength and durability of parts designed by our team, finite element analysis was performed for a maximum torque of 4,000Nm. Each component remained well within a safe range of deformation. The bracket (1) is used to hold the emergency brake caliper that slows the flywheel, while the bearing adapter (2) is the main component that will transfer power from the break disk to the handle.

![Mounting frame for emergency brakes.](image)

Figure 3. Mounting frame for emergency brakes.

![Adapter connecting handle to the braking system.](image)

Figure 4. Adapter connecting handle to the braking system.

IV. DISCUSSION

This project has given the researcher the ability to test the torque responses on the human arm according to their own specifications. Many hours of research and development went into creating a device that met the required specifications. Allowing the device to be used by a computer software such as LabVIEW, will result in an easy to use and easily replicable testing interface. Many of the parts in this build were chosen to be easily accessible and replaceable in case of failure or maintenance. Possible improvements to the design include a reduction in overall size through a better optimization of space. A weight reduction may also be necessary as the final project weighs 38.5kg. This will improve mobility of the overall system if it is needed to change positions on the mounting structure in the research lab.

V. CONCLUSION

CTD poses a threat to many workers and they may not even know it. The repeated torqueing motions they endure daily could cause serious harm in the long term. This project has the potential to have a very large effect on the health and safety of factory workers across the world. The research that will be conducted by this device could result in a large reduction in injuries to workers. The design can simulate the motions of power tools used in factories so that the client can study the effects of the motion on human test subjects.

Our design is simple to use as well as simple to construct. The components were selected based on their ease of use and ready availability. It consists of a simple mechanism of a spinning flywheel and a braking system to apply a torque to the handle. This will all be controlled by a computer using LabVIEW software. It will have the ability to test and record various levels of torque applied to the test subject. Through multiple design iterations, the team was able to create a design that is believed to have the best suited the needs of the client of the project. This design will also remain cost effective and under the given budget. It will also be able to remain well within the ethical guidelines for safety and effectiveness.

VI. ACKNOWLEDGMENTS

This project could not have been possible without the help of several people. The team’s teaching assistant, Sonali Rawat has worked tirelessly with the team’s facility advisor, Dr. Ting Xia, to provide feedback on assignments and reports. The project was created for the client, Simon Kudernatsch for the intent of research to be conducted in the BioDynamics lab. Under his specifications, the design was fabricated. Lastly, the university’s shop manager, Michael Reynolds has given the team the ability to understand what is feasible to manufacture given the resources available at NIU.
Abstract: Cardiovascular diseases are the leading cause of death in the world, and the prevalence is projected to increase in the next decade. The goal of this project is to develop a wearable device to continuously monitor cardiovascular activities over an extended period of time and detect abnormalities in early stage and act accordingly. The following device is a multi-sensor cardiovascular monitor. This device monitors the mechano-acoustic signals and detects and abnormality that leads to cardiovascular diseases (Arrhythmia, etc.). This wearable device will continuously record body motions, heart sounds and breathing patterns. These features make this device stand out among others in the market with the ability to share patient data in real time with doctors without being restricted to a single location.

Keywords: Heartsound, Mechano-acoustic, Abnormality Detection

I. INTRODUCTION

In the United States, more than 27 million Americans have experienced some form of cardiovascular disease (CVD), whether that was an ischemic heart event, stroke, or hospitalization for myocardial infarction. Also, (CVDs) are the leading cause of death globally, and in 2016, there were an estimated 17.9 million deaths from CVDs globally, which is representing roughly 31% of global deaths that year. From these deaths, about 85% of them were caused by heart attacks and stroke. According to the World Health Organization, people with CVDs or with high cardiovascular risk need early detection and management to either prevent or save their lives as appropriate. This project's goal is to use a wearable detection device to scan the cardiovascular region is needed to identify potential symptoms which then helps improve treatment response and accuracy of diagnosis.

II. DEVICE DESIGN

Here, we present a wearable device that consists of an accelerometer and a temperature sensor, to capture heart rate, body temperature, breathing patterns and cough sounds. The 4×4 mm accelerometer chip can record a wide range of vibrations on human skin, ranging from very low frequency (below 1 Hz) movements associated with the chest wall and body position to high frequency acoustic signals (up to 12 kHz) emanating from the heart and lungs.

This 3-axis accelerometer is highly sensitive with a low power threshold (0.0095W), adjustable BW per axis (0.5Hz-1600Hz for x y-axis and 0.5Hz to 550Hz z-axis), Vin (3.5V), 3Vout (3.3V) @100mA and is suitable for sports and health devices. The lithium ion polymer battery is a good fit for the device because they are thin, light, and powerful. This battery ranges from 4.2V when fully charged to 3.7 V with a capacity of 1200mAh for a total of 4.5Wh. This battery is embedded with protection circuitry to avoid overcharging and overuse by cutting off when completely dead at 3.0V. Below is a block representation of the device:

Figure 1: Block representation of electrical system

III. DATA ACQUISITION

The first idea toward designing this device started with acquiring the analog signals needed for study and reference, in other to get the data we used the ADXL335 and analog discovery digital oscilloscope then processed and analyzed the data with origin labs. To get the heart sound the sensor was places on the chest while held with medical tape, the oscilloscope was set to 1.6kHz sample rate. The position of the sensor for the heartbeat was logical to be on the chest allowing the z-axis to pick up the vibrations from the chest wall. This is not the same case for the cough signal, shortness of breath and deep breath, with that in mind the sensor were placed on the neck, chest and stomach which make it easy to analysis the results from these points allowing us to come up with an optimum position for the sensor. The data collected includes 1 cough signal (no cough/cough/no cough), 2 cough signals, shortness of breath and deep breath from the neck, chest, and stomach then the heart sound from the chest. The processing section which was done in origin labs started with truncating every unwanted signal from the cough and passing a band stop filter to eliminate the 60Hz noise. While processing the data the processing was not intense to avoid losing vital information.

IV. RESULTS

The analog data were processed and analyzed in origin labs; the data analysis is in time domain and frequency domain. In the time domain, the peaks were analyzed while in the frequency domain using Fast Fourier Transform; the power spectrum is used to find unique features of each signal. Time duration of the signals is also
vital; each signal despite being almost identical also varies in time duration, which also has its information. The signal from the chest has a duration from 0.25sec, the stomach signal time duration is 0.59sec and the neck signal has a time duration of 0.39sec. Time duration shows that the stomach signal has more information, followed by the neck signal, and the least is the chest signal.

The frequency range for the signals from the neck and stomach are almost identical while the signal from the neck is higher, this justifies the point mentioned above that the neck has more noise (distortion) which might be speech signal or pulse signal. This frequency range is also useful while trying to filter out noise from the neck signal; a lowpass filter can be used to retain the low-frequency component (f ≤ 35Hz) and reject the high frequency (f ≥ 35Hz).

Data for shortness of breath is also from the neck, chest, and stomach. Since shortness of breath is just a pattern, all three locations tend to have identical patterns, which looks like a cosine wave from physical inspection, the data from the chest seems to have more distortion. This distortion is also due to the placement and could be some heart sound. In the frequency domain all the signal from the neck and stomach has a frequency range of 0.1Hz-20Hz. In contrast, the chest signal ranges from 0.1Hz-30Hz. The signal from the neck has a primary peak of 2.2Hz with an amplitude of 0.016, the signal from the stomach has a primary peak of 1.4Hz with an amplitude of 0.012. In contrast, the signal from the stomach has a primary peak at 1.14Hz with an amplitude of 0.0047.

The deep breath pattern is identical to the shortness of breath; they both look like a cosine wave; the most distinctive difference is the distance between the crest in the signals. The distance between the crest in a deep breath is more than the distance in the shortness of breath. The signal from the neck has a frequency range of 0.1Hz-0.4Hz; the signal from the stomach has a frequency range of 0.1Hz-3.4Hz, while the signal from the chest range from 0.1Hz-5Hz. The signal from the neck has a primary peak at 0.4Hz with an amplitude of 0.039; the signal from the stomach has a primary peak at 0.6Hz with an amplitude of 0.033, while the signal from the chest has a primary peak at 0.4Hz at an amplitude of 0.0183.

The frequency range in the deep breath signal is smaller than the frequency in the shortness of breath; this because in the time domain, the deep breath signal is expanded with respect to time, while for shortness of breath, the signal is compressed in respect to time. Which causes higher frequency in the shortness of breath and lower frequency in the deep breath.

The sensor is placed on the chest where it picks up vibration from the chest wall. The signal consists of the s1, s2, s3 and s4. The physical difference between the heart sounds is the magnitude. The signals were processed in origin labs using a low pass filter and a band stop filter to eliminate the 60Hz noise.

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Drone-Enabled Sensing and Monitoring of Tree Canopies

Team 14

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Abstract—This multiphase project was proposed as a senior design project for the College of Engineering and Engineering Technology at Northern Illinois University by the Morton Arboretum, which is located in Lisle, IL. The ultimate objective of the project was to develop a universal sensor mount capable of accommodating small scientific instruments that can clamp onto tree canopy branches and is capable of being deployed and retrieved with a DJI Matrice 600 Pro UAV. The main motivation behind this project is that the tree canopy environment is difficult to study, as it cannot be easily accessed by humans. Research of tree canopies and the canopy environment is important, as it can help monitor tree health, monitor pest and disease outbreaks, provide a greater understanding of tree failure in storms, and support many other areas of biological research. Monitoring devices currently have to be deployed manually. The Morton Arboretum proposed that unmanned aerial vehicles (UAVs) could be used to more efficiently deploy monitoring devices onto tree canopy branches. The team conceptualized and designed a novel system capable of achieving the ultimate project objective. Prototypes of the universal sensor mount and deployment system were fabricated and tested. The universal sensor mount can be successfully secured to tree branches. However, further optimizations of the deployment system are necessary before the device is ready for integration with the UAV.

I. INTRODUCTION

There is a need for a more efficient method of studying the canopies of trees and the unique environment within the canopies. Current practices of manually deploying data collection devices in the tops of trees have multiple shortcomings. Deploying devices in tree canopies by hand is time-consuming, labor-intensive, and can result in damage to the tree. Additionally, there is always an element of personal safety risk to the person placing the sensors in the trees. Most of these shortcomings arise from the fact that tree canopies are difficult to access [1]. Thus, a method of deploying data collection devices onto tree canopy branches from unmanned aerial vehicles (UAVs), is desirable for The Morton Arboretum. Devices with similar motives have been developed, such as the system in [2].

To more efficiently deploy sensors and data collection devices in tree canopies, an electromechanical system was proposed, conceptualized, and designed that will enable a DJI Matrice 600 Pro UAV to deliver scientific research payloads to canopy branches ranging from 3 to 10 centimeters in diameter. The initial target weight for the system set by The Morton Arboretum was 3.0 pounds. The other major design requirement was that the universal sensor mount (USM) needed to be capable of accommodating sensor packages weighing up to 250 grams.

To meet the above design requirements, a system consisting of three main subsystems was designed and prototyped. The three subsystems include a USM, deployment/retrieval system (DRS), and controller system (CS). Sensors and other data collection devices can be attached to the USM. The USM is the subsystem that gets deployed onto tree branches and left behind for a data collection period. The USM is resistant to adverse weather, as it may remain deployed on branches during rain and thunderstorms. The USM incorporates two torsional spring clamps to passively attach to tree branches. The gripping mechanism is actuated by a servo motor on the DRS, which is suspended from a pole beneath the UAV. The USM is secured in the housing of the DRS until deployment by a secondary servo motor. Both servo motors in the DRS are capable of being powered from an outlet underneath the UAV. To retrieve the USM, the deployment DRS end effector can be swapped out for a simple, retrieval hook to capture a cable loop attached to the USM. The DRS servos will ultimately be controlled by the stock DJI Matrice 600 Pro UAV controller with a channel expansion kit.

II. MATERIALS AND METHODS

Due to the significant weight constraint for the design, weight was the most important factor in material selection for the USM and DRS. Consequently, the team’s design utilizes both machined aluminum components and parts 3D printed from polylactic acid (PLA) filament.

The USM designed by the team is depicted in Fig. 1 and the deployment system (DS) design by the team is depicted in Fig. 2. The USM consists of an extruded PLA body, two aluminum 6061 rotating clamps, two music-wire steel torsional springs, and two aluminum 6061 adjustable rigid clamp arms. The torsional springs and rotating clamps are held in position on the USM body by press-fit extruded PLA plugs. To ensure that the USM and a 250-gram payload could remain safely secured to the target range of tree diameters, torsional springs with constants of 2.93 in.-lb./rad were selected. The top of the USM body has arrays of holes to allow the arboretum to attach a wide range of payloads. Based on the diameter of target tree branches, the fixed clamps can be
fastened to one of four positions to ensure that the USM has sufficient torque to remain secured to the branches.

The DS design in Fig. 2 consists of an extruded PLA housing, bearing block, USM mounting brackets, and incremental angle hinge. Furthermore, the system incorporates an aluminum 6061 drive shaft, two aluminum 6061 roller arms, and two nylon rollers. One servo motor rated at 35 kg-cm rotates the shaft and another, identical servo motor is used to lock and unlock the USM in the housing by rotating a fixture that indexes with the USM body.

III. RESULTS AND DISCUSSION

The original USM and DS designs utilized aluminum and extruded PLA components. However, in response to the restrictions introduced by the COVID-19 pandemic, the team redesigned the USM and DS to produce the initial prototypes in Fig. 3a, which consist nearly entirely of 3D printed PLA components.

The USM prototype was tested across the range of target tree branches with a 280-gram payload and the device remained firmly secured to tree branches as desired, even when disturbances were introduced to the tree branches. The USM prototype also properly indexes within the DS prototype.

To test the DS prototype, the servo motors were connected to a power supply and controlled with potentiometers and an Arduino Uno microcontroller as shown in Fig. 3b. The secondary servo motor used to lock the USM in place functioned as desired as long as the servo remained energized. However, before the drive shaft servo could supply sufficient torque to open the USM clamps, the setscrew joint between the servo coupler and drive shaft sheared the drive shaft PLA. For future revisions of the DS prototype, the authors recommend machining the drive shaft from aluminum 6061 as was originally intended and increasing the mechanical advantage of the roller arms.

IV. CONCLUSIONS

Overall, to progress towards The Morton Arboretum’s ultimate goal of deploying and retrieving small scientific instruments on tree canopy branches with a DJI Matrice 600 Pro UAV, the authors have conceptualized, designed, and prototyped components of a novel system. An optimal design was selected that consists of three main subunits: the USM, DRS, and CS. The team successfully completed the first phase of the design project by producing a functional prototype of the USM. The team also made significant progress in the second phase of the project by designing, fabricating, and testing an initial prototype of the DS. Further optimization of the DS is recommended before integration with the UAV.

ACKNOWLEDGMENT

The authors would like to thank The Morton Arboretum for providing the opportunity to work on this project. The team specifically thanks Chuck Cannon and Colby Borchetta of The Morton Arboretum. The team would also like to thank their advisor, Dr. Sachit Butail, and teaching assistant, Sandhya Chapagain. Throughout the project they provided guidance and expertise that was beneficial to the team. The team also thanks Nicholas Potsek of Buffalo, Wyoming for his machinist work. Lastly, the team would like to thank its educational institution, Northern Illinois University.

REFERENCES


Perfusion Bioreactor Apparatus for Studying Osteoblast Proliferation

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Abstract—Research-aided development of synthetic tissue constructs resembling natural tissue shows promise for expanding the potential of regenerative medicine. Advancements in this field are enabled using devices that support a biologically active environment. Specifically, there exists a demand within academia for a low-cost, high output bioreactor to facilitate study on osteoblasts proliferation and differentiation. Our goal was to design and manufacture a perfusion bioreactor capable of testing six individual samples. Our perfusion bioreactor was engineered to achieve a specific range of shearing stress and pressure at a sample’s surface; while sustaining optimal conditions for cell culturing. SolidWorks 2019 and Ansys CFD 2019 were used for prototype development. The simulation testing generated data that was analogous to analytical calculations. This perfusion bioreactor comprises of four components and is readily assembled. The device allows for experimentation on numerous samples and enables repeated use. Potential for modification of bioreactor tubing exists to allow for variation of cell media properties in future cell studies.

I. INTRODUCTION

According to the United Nation, the World Health Organization, governments, and professional and patients' organisations have declared 2000-10 the “bone and joint decade” with the aim of improving the health-related quality of life of people with musculoskeletal conditions [1]. Recently, there has been significant investment in tissue engineering as researchers seek to enhance treatment for these conditions. The development of bioreactor devices provides scientists with the means to perform targeted research at the microscopic level.

This paper presents a perfusion bioreactor apparatus which enables study on the effects of osteoblast proliferation and differentiation when subjected to fluid shearing stress ranging from 0.8 to 3.0 Pa and relative pressure on the order of 7 kPa. The device is composed of nontoxic, autoclavable, 3D printable polycarbonate filament whose multichambered design capable of simultaneously experimentation on six individual samples. The device is inexpensive, compact, durable, and simple to assemble. The perfusion bioreactor works in conjunction with a peristaltic pump, cell media reservoir, and incubator. The goal of this apparatus is to simulate a biologically stable environment, while keeping cell media fluid properties stable.

II. MATERIALS AND METHODS

A. Prototype Design

The symmetrical, split-flow bioreactor design efficiently separates incoming cell media, directing it to individual samples. Consisting of four components, the bioreactor can be disassembled (Fig. 1) for cleaning and inspection. The first component, the inlet cap, connects the bioreactor to the peristaltic pump tubing. The second component, the fluid distribution module, gathers and directs incoming cell media to a sample. The next component is used to load the samples and position them in place. Finally, a reservoir collects cell media that has passed over the samples.

B. Analytics of Cell Media Properties

The bioreactor is designed to be compatible with a base medium of 1:1 mixture of Ham’s F12 Medium Dulbecco’s Modified Eagle’s Medium whose fluid properties are comparable to those of water. The mass flow rate (used in CFD simulations) output from the pump was verified experimentally. Basic governing equations for fluid flow and the provided properties of the cell medium were used to determine inlet boundary conditions and shear stress at the surface of a sample.

\[
\dot{m} = \rho AV
\]  

\[
\tau = \rho \frac{d\mu}{d\gamma}
\]

ANSYS CFD was used for simulating the flow of cell media within the apparatus. This was performed with the assumption of steady, incompressible, and fully-developed fluid flow.

C. Manufacturing Process

The perfusion bioreactor is designed to be 3D printed using hygroscopic, medical grade polycarbonate. Polycarbonate is autoclavable and can withstand temperatures up to 140°C while maintaining the strength and form. Printing may be done with Fortus Classic by Stratasys using PC-ISO (translucent) #310 20400 filament and PC BASS support material. This process has a printing tolerance of ±.127 mm.
III. RESULTS

Variation of the tubing diameter and length of the bioreactor fluid distribution module affected the mechanical fluid properties of the cell media. Various tube geometries were tested to attain the required shear stress and pressure ranges required for research. The effects of varying tube geometry are presented in Table 1. Using the simulation data, it was decided that the fluid distribution module produces the necessary range of shear stress and pressure at the sample face using 8 mm diameter tubing.

<table>
<thead>
<tr>
<th>Tube Length</th>
<th>Tube Diameter</th>
<th>40 mm</th>
<th>400 mm</th>
<th>1 m</th>
<th>6mm</th>
<th>8mm</th>
<th>10mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear Stress at center (Pa)</td>
<td>0.833097</td>
<td>0.83126</td>
<td>0.82857</td>
<td>4.27851</td>
<td>1.78162</td>
<td>1.13044</td>
<td></td>
</tr>
<tr>
<td>Shear Stress near edge (Pa)</td>
<td>0.970442</td>
<td>1.04298</td>
<td>1.13795</td>
<td>3.67917</td>
<td>1.7826</td>
<td>1.09331</td>
<td></td>
</tr>
<tr>
<td>Pressure at center (Pa)</td>
<td>2451.028</td>
<td>3937.616</td>
<td>9780.570</td>
<td>8170.904</td>
<td>7901.351</td>
<td>6749.539</td>
<td></td>
</tr>
<tr>
<td>Pressure near edge (Pa)</td>
<td>2447.310</td>
<td>3934.508</td>
<td>9763.280</td>
<td>76383.950</td>
<td>7144.23</td>
<td>6288.048</td>
<td></td>
</tr>
</tbody>
</table>

The distribution of shear stress and pressure on the face of the sample varied independently of the tubing diameter. The manner in which the cells are seeded onto a sample disc results in the majority of cells gathering near the center of the disc. Given this, shear stress and pressure values were measured with respect to the radial distance from the center of the sample. These results are presented in Figures 2 and 3. As expected, shear stress and pressure are higher at locations further from the center of the sample. Varying the length of distribution module tubing did not show significant changes on the shear stress at the sample surface, however, data shows that pressure increases proportionally when tubes are elongated. The pressure variation with respect to radial distance from the sample center is attributed to the difference in diameter of the tubing and the sample disc.

Figure 2: Variation of Shear Stress at Sample Surface

Figure 3: Variation of Pressure at Sample Surface

This work marks an important step in the development of appropriate tube geometries. Moreover, the use of inexpensive materials and simple geometry modifications makes this device easily adaptable for inducing a variety of shear stress and pressure ranges in future research.

IV. CONCLUSIONS

A perfusion bioreactor apparatus was designed for studying the effects of shearing stress and pressure exposure on osteoblast proliferation and differentiation. Various bioreactor tube geometries were designed and tested through simulation. Additionally, the 3D printed manufacturing process enables the possibility of modifying bioreactor tubing geometry for future study.

ACKNOWLEDGMENT

This work was accomplished with the support and guidance of Dr. Vahabzadeh and Dr. Salehinia.

REFERENCES


R0V3R: Robotic Guide for the Blind

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The purpose of this project is to develop a product that gives blind people the independence to be able to safely travel on their own. The robotic guide, R0V3R, is equipped with ultrasonic sensors to help users move in a straight line and to detect numerous obstacles the user may encounter. The robot is interactive with the user and can verbally describe the environment around it. With a built-in charger and its light weight, the robot makes traveling much more feasible for the visually impaired.

I. INTRODUCTION

Current solutions to the guidance of the visually impaired while functional, are not a perfect fit to the ultimate goal of independence and safety. Alone an individual can only navigate with a cane through an area in which they are familiar. Guidance by dogs is more practical but has limitations, as they are unable to read signs and cannot navigate effectively in new areas. Human guides are the most desirable, but are not always available to assist the blind. A feasible solution to the problems that blind individuals face on a daily basis is a robot to help guide them through their environment. A guide robot does not require constant attention like a dog and would give individuals a sense of independence and safety, in spite of their handicap. The robotic guide provides a more encompassing solution to assist the vision impaired. The blind struggle to walk on a straight path unassisted, the robot tracks straight when guiding until an obstacle or point to turn are located. Sensors in the front, sides, top, and bottom of the robot notify the guide of potential issues while on route. When the sensors are triggered the robot guides the user around the obstacle safely while they hold onto a handle connected directly to the robot. Another sensor locates objects above that could cause a risk of hitting the user. The robot can interact with the operator through voice commands, and when addressed be able to give a response. This is mainly done through Microsoft Seeing AI. Microsoft Seeing AI utilizes R0V3R’s built-in camera to view its surroundings and verbally describe it via R0V3R’s speaker. The robot has a safety feature that only allows it to move when the user is holding the handle, eliminating the possibility of the guide leaving the user in an unfamiliar place. It is portable as to be carried upstairs, and rugged for guidance when off sidewalks and streets. R0V3R is water resistant so it can still operate in the rain. Using a rechargeable battery, the robot will replenish the energy that was expended while traveling and interacting with the operator. The robotic guide will help to alleviate the strain and dangers of traveling alone, returning to the visually impaired a sense of confidence and independence.

II. MATERIALS AND METHODS

A common tool blind individuals use is a white cane. Blind individuals use white canes by extending them out in front of themselves and tapping around for any obstacles within their path. R0V3R expands onto the design of a white cane and transforms it into a functional robot. White canes are always slanted at an angle with the end section tapping around for objects. R0VER’s handle is also slanted at an angle, but with wheels attached to a plastic casing at the end of it. Instead of having to tap around surroundings like a white cane, R0V3R moves itself with its all-terrain tires. Attached to the casing are ultrasonic sensors that detect obstacles and move the robot away from any obstacles within its path.

Figure 1. R0V3R interacting with user

The sensors are mounted above, below, and on all sides of the robot for a full 360 intake of its surroundings. This allows the robot to detect obstacles at, above, and below chest level. Obstacles at and below chest level include people, cars, and drop offs such as cliffs. Obstacles above chest level are equally as important due to head injury that low hanging tree branches or signs can cause. A rechargeable battery directly powers the voltage control board in R0VER. The voltage control board connects to the four motors that drive the robot, and the computer. The computer controls the interactions with the speaker, mic, on/off button, Microsoft Seeing AI, and the information from the other various sensors. The casing contains all of these components within it. The conduit handle attached to the casing and tires is in the shape of a “U”. This
ergonomic handle allows the user to have a greater hold on the device as well as allowing for easier interpretation of the robot’s movements. When the robot’s tires start moving away from an obstacle, it will be easier for the user to feel and sense what direction the robot wants to move in. The user will be able to feel what side of the handle is drifting away from their hand, telling them to follow the robot in a certain direction. This “U” shaped design also adds another point of contact between the handle and the casing. By having two contact points it allows for an overall less load on the points of contact, which allows for a stronger and longer connection between the handle and casing. The handle can expand and contract in order to accommodate to each user’s height.

The battery is what provides power to the whole system. It is connected to every component that requires a voltage to operate. For our system, we require a battery that can supply enough voltage to our motors, GPS, raspberry pi, and all other peripherals. Out of all these components, the one with the greatest voltage requirement is the motors. We will be using 12V motors, and because of this we will be required to have a 12V battery. The motor control system is a vital part of our system. It is going to be what ultimately guides the user around obstacles that are in front, above, below, or to the sides of them. It does this through 3 different components that give commands on how the motors should run in any given circumstance. A block diagram of this can be seen in the Figure 3 below.

![Figure 2. Design of R0V3R with casing and conduit handle](image1)

III. ELECTRONIC COMPONENTS

The raspberry pi serves as the brains for the motor control system. It is the intercommunication between the motors and the sensors. It holds and runs the code that will tell the motors when and how-to operate. R0V3R has a programmed script in Python that consist of if-then statements. These statements use the inputs from the ultrasonic sensors and convert that into different levels of voltage that go into each motor. This process of controlling the motor speed in Python is called pulse width modulation. Pulse width modulation uses different duty cycles in the code to change the speed of the motors. It does this through the L293D chip that has the transistor built into it. The raspberry pi does this all through its GPIO pins by assigning the sensors as inputs and the motors as outputs. The L293 chip is used in R0V3R to allow for the PWM functionality to work for the motors. The GPIO output comes directly from the raspberry pi, which is used to allow current through the transistor. The diode of this circuit is only used to prevent voltage spikes for when the transistor is activated. This circuit uses the PWM functionality from the raspberry pi to control the speed of the motor.

IV. IMPACT TO VISUALLY IMPAIRED

With a design like R0V3R’s in the market, it will inspire more products to become available for the blind community. This robotic guide is designed with materials that do not make the guide very costly. Almost everyone will be able to afford the robotic guide. No matter where the user is at globally, the robotic guide will work. The design includes all-terrain tires that allow users to use the guide almost anywhere. A charging cord is built into the robot so no matter where the user is, as long as there is an electrical outlet nearby, the user will be able to charge the robot as needed. With R0V3R, the blind community will not need human guides and will not feel like an imposition to others. The design allows for blind individuals to feel like any other member of society.

V. CONCLUSION

The robotic guiding device provides an effective and efficient way for the visually impaired to travel. Tasks others find simple, such as walking in a straight line, are impossible for the visually impaired. With ultrasonic sensors and features like Microsoft Seeing AI, R0V3R gives blind individuals the independency and support they need.

ACKNOWLEDGEMENTS

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REFERENCES


Multi-Parameter Sensor Device to Provide Continuous Indoor Environmental Monitoring in Hospitals

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Abstract—This paper describes the functionality of a device that is equipped with multiple environmental sensors that collect particulate, temperature, humidity, and differential pressures in a hospital setting in a small package. Data is transferred via a National Instrument microcontroller to a cloud database to be continuously monitored for root-cause analysis to protect public health interests.

I. INTRODUCTION

In the medical field such as hospitals or operating rooms have a need to protect the health and safety to all inhabitants residing in the buildings. To accomplish this, the facility monitors the indoor environmental qualities with upmost scrutiny. Air qualities that are monitored are but not limited to are the amount of particulate matter in the air, temperature, humidity, and air pressures within any given area. The systems that are available in today’s world are either bulky in physical size, expensive, inconsistent or a combination of all three. What is not currently available is a multi-sensor singular package that has a smaller physical footprint with accuracies that conform to current hospital standards which can also monitor in real-time and can be produced in an inexpensive manner.

In this paper, we describe a new device that can take mechanical components which measure a physical measurands such as airborne particulate, pressure differentials, humidity, CO2 levels, and temperature. These mechanical components need to then be transduced to an electrical component such as resistance, current, or electric potential to be measured to correspond to the physical property measured. The data is packaged in a singular format that is sent to a cloud database continuously to be easily read by the user for environmental information wherever the device is installed. The sensors incorporated into the device are a particle counter, temperature and humidity sensor, differential pressure sensor, and a CO2 level sensor that can completely ‘paint a picture’ of the given environmental surroundings.

II. MATERIALS AND METHODS

Through the many ISO standards for particulate counters in a health care setting like the ISO 14644-1 [1], USP 797 [2], and much input from Forensic Analytical Consulting Services (FACS), the best company for the sensor was found. After finding Particle Plus, much discussion was taken with the company to get a custom OEM Particle counter that was capable of measuring particulate in varying size from 0.3µm – 25µm using laser scanning through a pump inlet funnel. Since Particle Plus did not have an OEM version of this sensor, they supplied a custom unconstructed version of their very common and proven Model 8306 handheld particle counter. This sensor was ultimately chosen because of its ability to measure up to 6 different channels of particulate size, its OEM capabilities for production use, and its compliance with ISO 22501-4 [3] calibration methods with its built in Pulse Height Analyzer.

There are no ISO standards for pressure differential monitoring, but there was much input from FACS to the level of accuracy they required and range of measurement. The unit of measure that is used in hospitals for pressure differential between 2 separate areas is inches of water column (W.C.). The way that the sensors measures differential is the same as a manometer. While there is not a manometer inside the sensor, the sensor works from a flexible capacitive diaphragm inside the sensor that is exposed to the separate pressure ports on either side of the diaphragm. As pressure builds on either side of the charged diaphragm, the current that exits the sensor is either increases or decreases due to the increase in capacitance. This output current is read at a high precision 250 ohm +/- 0.05% resistor as a voltage. This voltage at the resistor is then measured and converted by the controller to inches of water column. The Setra Model 264 pressure differential sensor was chosen due to its simple design, high accuracy, and ease of calibration with a potentiometer on the side that is accessible with a small flat head screwdriver.

Many other environmental conditions were discussed to add to the unit like sound levels, temperature, motion, relative humidity, and CO2 levels. The Sensiron SCD30 sensor was chosen because of its low price, ease of operation with Modbus communication, and low inlet current and voltage draw. This sensor is capable of measuring Tempurature, Relative Humidity, and CO2 levels. Motion and Sound monitoring were excluded from the unit due to privacy concerns in hospital settings.

When designing a sensor package that will be used in a healthcare setting, many requirements must be followed. The packaging needs to be made of materials that are not susceptible to corrosion, will not deteriorate from common hospital cleaning products, are entirely free of sharp edges or burrs, and will not have any openings to potentially high current circuitry on the inside of the unit. The unit is designed to be mounted on the wall of any hospital area. It needs to be secure to the wall and not stick out normal to the wall past 3.5 inches. The packaging design and components selected were chose with this dimensional tolerance in high regard.
For the purposes of controlling and measuring all software functions of the unit, the National Instruments My-RIO Model 1900 controller was selected due to its easy to use programming environment, WiFi capabilities, extremely durable design, and large number of I/O pins in a multitude of voltage and current ratings. Labview is a National Instruments program that is used to program and control all the company’s controllers. Labview uses blocks interfaces and virtual interface programming instead of lines of code. As the code runs, the flow is tracked, and errors are shown in real time as the code runs to make debugging and troubleshooting the code extremely easy.

This unit will be running 24/7 and continuously monitoring data at a rate that can be defined differently for each hospital based on their individual requirements. Based on this, the storage and analysis of the data must be very robust and easily integrated to many different applications. InfluxDB is an internet cloud-based server that can be configured to read, scale, and graphically display large amounts of data for analysis and real time monitoring. Below is the graphical representation for Temperature, Relative Humidity and CO2 Levels:

The server for this unit was configured to display the data for all 5 outputs as a rolling average to be graphically displayed. Essentially, the data is being continuously monitored and stored, but the only thing that is displayed on the graphs are the average for a certain window of time (last 5 minutes, 10min, 15min, etc). This window will be configured for each hospital based on their needs. The rolling average approach makes small 1-2 second spikes in condition levels that do not cause as high of a spike in the overall monitoring. The information being displayed on the InfluxDB interface are the particulate levels for all 6 particulate sizes, pressure differential, Temperature, Relative Humidity, and CO2 levels.

### III. RESULTS AND DISCUSSION

#### A. Data Analysis Verification

The system successfully transduced the physical measurands of particle counting, temperature, CO2, and humidity into electrical aspects. These electrical aspects are then, through Labview code, correlated back into recorded measurements. These recorded measurements are sent to a cloud server in excel format to download for data analysis. The packaging of the unit was designed in such away that it met all hospital requirements and did not distort the data in any way as seen below:

### IV. CONCLUSION

An all in one sensor package was designed for the use in hospitals. Particulate is evaluated for the entire range as specified in the ISO 14644-1 [1] and USP 797 [2] standard for hospital particulate monitoring. Pressure differential is monitored through highly durable flexible plastic tubing with a range of +/-0.25 inches of water column to a tolerance of +/- 1.0%. Inside the unit is also a sensor card that monitors temperature, relative humidity, and CO2 levels. The packaging design is made of materials that will not corrode over time, is free of sharp edges and burrs and fits within 3.5 inches of the walls surface. With the InfluxDB cloud server analysis tools, the data that is exported from the National Instruments My-RIO Model 1900 controller is stored and displayed in an easy to read manner for the greatest ease of use for hospitals.

### ACKNOWLEDGMENT

David Brinkerhoff and John Martinelli from the industry sponsor Forensic Analytical Consulting Services (FACS) provided all funding for the project. FACS also provided design requirements that were used and continuously updated through the lift of the project that drove the design of the unit.

Dr. Monsour Tahernezadi and Fahad Alqahtani met with the team every week to ensure that progress was being made on the project and supplied support when needed by the team.

Javier Arellano was a great resource for coding in Labview. His years of experience with Labview and the My-RIO controller through his career at Collins Aerospace proved to be a huge asset to the project.

Thomas Grillio from Particles Plus was a technical representative for the Model 8306 particle counter.

Dick Pansire from Setra was a technical representative for the Model 264 Pressure Differential sensor.

### REFERENCES


Treadmill Actuation System
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Abstract—Along with staff from the engineering team at Life Fitness, an alternative treadmill actuation system has been developed to add to the available methods to incline a treadmill. Under various project requirements for compatibility, the design will act no different than the current actuation methods to the end user. The benefit is gained by adding greater flexibility to the design of products. In order to keep costs low and not impact the price of the final product, known materials were used along with current components. No additional operations will be needed compared to the original design, which will help maintain production and assembly times.

I. INTRODUCTION

A treadmill is made up of several key components, including the deck, belt, motor, actuator, arms, and the control panel. The belt is powered by the motor which propels it around two rollers on either end of the deck. The speed of the belt as well as the inclination is controlled by the user on the control panel. The belt is a consumable part that will need to be replaced during standard intervals of maintenance. An important requirement for a viable actuator system is easy replacement of the belt.

Life Fitness’ signature treadmill product line consists of a front housing which includes the motor. The housing contains approximately 168in² (1084cm²) in area. Their primary commercial customers are a wide range of fitness clubs and gyms. An interesting trend in this industry is to utilize smaller facilities to minimize expenses, while providing more equipment for members to use. The Client (Life Fitness there forth) has acknowledged that the extra space in the front housing is too large for an increasing amount of customer’s who are trying to maximize space. These customers, known as HVLP (High Value-Low Price) gyms, are taking an increasing portion of the market’s membership share, with Planet Fitness seeing a 25% YOY member growth since 2010 [1]. In order to be more attractive to this type of market, they have brought their challenge to Northern Illinois University to develop the actuation system.

There are similar functioning products for compact treadmills on the market but are made for different applications. One of these iterations are concave styled running decks, which are usually non-motorized with no ability to incline. These treadmills are made specifically for running to keep the momentum of the belt moving under the force of the user’s last push off. Because they are specialized machines, they are expensive and therefore not realistic in mass purchase for commercial use. Utilizing a compact form-factor without additional costs to the consumer will be an attractive package.

II. MATERIALS AND METHODS

The primary material used was A500 steel because of its mechanical properties. It provides a large yield strength to withstand the force that will be exerted against it.

An important feature to maintain is an accessible way for a technician to change the belt on the treadmill. In order to fulfill this requirement as shown in Figure 2, a pair of supports are included to remove the actuator assembly. The supports are held together with two bolts on either side and will assist with the force dissipation across the system. The highlighted brackets will be welded to the frame of the treadmill and legs of the lift. The supports are fastened in place with those brackets and can be removed while the machine is in a stationary position. This will help in the event the work environment is tight and the machine cannot be moved. The yellow supports on either side of the lift will be welded to the underside of the treadmill frame and will act as the pivot point the actuator will exert a force around.

Fig. 1: A 3D Model of the actuation system located within the treadmill prototype. The front of the frame is on the right and is subject to final revisions.

Fig. 2: A close-up view of the proposed actuation system.
III. RESULTS AND DISCUSSION

The total weight of the design is 60 lbs (27 kg). A goal of production cost per unit was to be less than $100, with the prototype costing $140. This is still within an ideal range as buying in larger quantities will greatly reduce the cost at time of production.

Complex geometry was used to determine the optimal angles needed to achieve the required inclination of 15%. The Client provided that an angle of 8.5° must be made between its resting position and the lift frame wheel to attain 15%.

Because we are using A500 steel, we realize a very low level of material deformation (.004in) from the force of the actuator. The force is concentrated at the bracket that holds the actuator and is distributed across the top support. The data shown is for a male in the 90th percentile weight exerting three times their mass (968 lbs. combined with the mass of the treadmill) during physical activity. This is the largest force the system will experience during normal user operation and the simulation is visually exaggerated to highlight these findings.

Having a high factor of safety provides peace of mind and communicates a high quality and well-engineered product. The data shows a minimum factor of safety of 8.4. This value is seen near the welding of the upper arms and lower rack. Much of the system sees a factor of safety of nearly 14.

Another test was conducted for a case of misuse with 2000 lbs (907 kg) of acting force. The factor of safety remained at least 1.9 throughout the system and experienced .01in (.25 mm) of deformation.

IV. CONCLUSIONS

Life Fitness shows ambition in the development of the project to diversify their product line and respond to new customer expectations. As the fitness and gym industries continue to evolve their business models, such as with HVLP gyms, it is important to adapt to the needs of the customer. As the leader in commercial fitness equipment worldwide, the envisioned product will help Life Fitness to offer a machine with a smaller footprint and the same excellent reliability as previous models. Offering compact equipment with an attention to quality will protect the existing clientele and retain them from the competition. It may also attract other customers that have overlooked their brand in the past because they did not offer a product that had fit their needs. The design outlined will address the lift system’s compatibility with the project, allowing Life Fitness to progress in development.

ACKNOWLEDGMENT

Our team would like to acknowledge and thank the staff at Northern Illinois University who has assisted in the progression of this project including our team advisor, Dr. Sachit Butail, and teaching assistant, Witenberg Santiago Rodrigues Souza. We would also like to acknowledge Peter Kanakaris and Juliette Daly from Life Fitness for bringing this challenge to NIU and dedicating their time and resources for our success.

REFERENCES

Portable Take-home Device for Measuring and Recording Vital Signs of Patients.
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Abstract - Vital signs are very important to all medical patients and they are the simplest way to assess one's health. Implementing a device that mimics routine vital-monitoring could change the medical industry. Patients could live their lives as if nothing was wrong with them while being under constant medical supervision. This device would be able to send real-time data from the vitals stated above to medical professionals via wifi. The device will be non invasive and compact while also being smooth and sleek in appearance. The portable vitals box integrates a thermopile, a Photoplethysmogram and Electrocardiogram, and a linear strain gage. The integrated sensors will be able to measure and read temperature, heart-rate, blood pressure, oxygen saturation, and respiration rate; all while sending the recorded data to a mobile app via bluetooth or wifi.

I. INTRODUCTION
Everyday around the world there are people who need medical attention, in a hospital, at home, or in a remote area without electricity; With the need for medical attention also requires medical services, specifically some of the general practices that are often overlooked. The Take-Home Vitals Box will be used to take five vitals from a patient and send their information via WIFI or cellular data to a hospital where they will be closely watched over. Five vitals will be monitored, and they are heart rate, respiratory rate, temperature, blood pressure, and oxygen saturation.

The goal is to monitor the patients' health without interfering with their everyday life; This includes things such as doing chores around the house to even being able to go to work while the device is in use. It may also help discover and better understand strange medical phenomenons [1]. The Vitals Box can read and record the listed vitals, store the results, and also send the data wirelessly to a mobile app or laptop. To be able to monitor patients in the comfort of their own home and not take up resources and space at a hospital will change healthcare.

II. DESIGN FEATURES

A. Sensors and Microcontroller
The entire system will be programmed and controlled by an Arduino Uno microcontroller, which supplies 5 volts to the sensors and hardware and through some electromechanical means gets transduced into an output voltage. The Arduino will then take the input voltages from each sensor separately to interpret the data into different data, corresponding to each individual sensor and vital sign. Any additional circuitry that is required for the sensors will also be incorporated into the PCB. All sensors are integrated using multiplexing; each reading will output its own specific plot.

A ZTP101T thermopile will be used to read the patient's temperature. Blood pressure will be calculated using the MAX 86150 three-in-one device. The ECG will require the patient to hold their finger on the finger pad to read heart rate. The pulse-oximeter(PPG) will also require the patient to put their finger to the device, or use two electrode pads, to read...
the oxygen saturation levels along with heart rate. Strain gauges will be used to read respiratory rate by measuring the amount the diaphragm expands [2]. Incorporating a blood pressure sensor into the device differentiates The Take-Home Vitals Box from products that are already on the market. Although there are few of its kind not one has a way to measure blood pressure. The device is expected to have a battery life of around two days. This will minimize the amount of down time for the device and lower the amount of time the patient is stuck next to an outlet. Using an alternative method for power was not feasible for the given time so using a lithium battery with a long run time was the best option. All sensors must have an accuracy of one-tenth of a percentage to follow medical quality.

B. Power Supply

To power the take-home vitals box a rechargeable battery system was used. Two 3.7V lithium ion batteries were used each capable of 2200 mAh. This allows the device to run all day while supplying a minimum of 5 volts to the device.

C. Housing

The Vitals box will be strapped in place to one's upper arm, with adjustable velcro straps. In this location the strain gage and the thermopile will be the only sensors that are not encased in the housing. The placement on the arm allows easy access to the device, and allows the thermopile and strain gage to access their specific spots on the body; ribcage and ear.

D. Wireless Bluetooth Capabilities

The Vitals box will be attached wirelessly to the patients left or right arm. Data on the patient's vitals will take place via bluetooth. A HC-06 chip is placed in the lid of the device allowing the Arduino to communicate with a serial monitor on an Android device or PC.

III. TESTING/EXPERIMENTATION

Fig. 2. ECG Waveform plot, mV vs time(secs), measuring heart-rate.

In order to test the accuracy of the system a set of experiments were conducted using the scientific method. Most sensors required some calibration converting raw analog data into meaningful measurements. Calibrating the infrared(IR) sensor used for reading body temperature was done using thermocouple readings on a common heat source. Thermocouple readings were compared to IR readings creating a linear relationship. A similar method would have been used with strain gauges for the respiratory device.

IV. CONCLUSION

Progress has been made to produce 4 different output plots that all vary depending on the recorded values; the outputs of the ECG, PPG, respiration rate, and heart rate. Blood pressure will not have a plot, but will be measured. The device will be able to send information on patient's vitals wirelessly, but the intended application for the Vitals box is domestic use. The data can be documented and potentially find any underlying issues before they become a problem. The low cost of the components means that the product can be manufactured for cheaper than current products on the market sitting around only $100 for the entire device. The ability to mass produce the Take-Home Vitals box means that it can be distributed to the places that need them the most due to lack of medical personnel, and resources.

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REFERENCES

Smart Brace for Continuous Monitoring of the Knee Joint

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Abstract—Over 100 million people suffer from chronic knee pain and about 1 million are admitted to the ER for serious knee injuries. Since it is the most common injury in America, knee injuries are the most prominent cause of missing workdays and have led to some professional athletes losing a lot of money or their careers. To combat this, a smart brace was designed to continuously monitor the health of the knee joint by measuring the acoustics produced by the bones, muscles, and tendons of the user. These measurements are then stored in an app accessible to the user via their phone or computer. The recorded measurements can also be shared with the user’s physician to reduce the number of doctor visits.

I. INTRODUCTION

The human knee consists of four main components that are vital to determine knee health: Articular Cartilage, Meniscus, Femur, and Tibia (Figure 1). To prevent discomfort and maximize mobility, the Articular Cartilage is a slippery substance that covers the Patella to ensure that the bones rub smoothly against each other while in motion. Additionally, the Meniscus is a tough and rubbery cartilage located between the bones that acts as a “shock absorber” against sudden force and strain applied to the knee joint. With repetitive strain and age, the Articular Cartilage and Meniscus begin to deteriorate, causing bone-on-bone contact, which is the most common injury reported across all ages.

As the bones in the knee joint rub against each other, they produce sounds that relate to the quality of the joint that may not be audible to the human ear. These sounds are referred to as acoustic vibrations and can be measured as a periodic or irregular sound wave, depending on the type of motion. The main component of these sound waves that can be used to measure and monitor knee health is the amplitude of the sound wave. The amplitude correlates to the height of the sound wave and the higher the amplitude, the louder the sound. This correlation contributes to how the sounds from a knee joint can be monitored and measured for many issues. When the Articular Cartilage and Meniscus are in good condition, the friction between the Femur and Tibia is significantly reduced, resulting in a sound wave with a low amplitude. As these parts begin to atrophy, friction between the bones will increase, causing the amplitude of the sound wave to get higher and the volume to get louder. Large amounts of continuous friction in the knee joint increases the likelihood of injury and chronic pain.

Since most of the sound waves created by the knee are not audible to the human ear, the smart brace will utilize piezoelectric and MEMS sensors, which can measure the inaudible sounds of the knee so that the users and their physicians can keep track of their knee joint health to prevent future injuries or chronic pain. This application can also be used to monitor rehabilitation after surgery.

II. EXTERNAL DESIGN

A. Sensor Placement and Knee Brace Design

The base design for the smart brace is a compression sleeve with modifications to help combat any environmental and occupational hazards that the user may encounter. The compressive nature of the sleeve allows the piezoelectric contact sensors to be in constant contact with the user’s skin to ensure quality measurements. The material of the sleeve is a combination of spandex and soft fibers that increases comfortability and adjustability for the user.

The two piezoelectric contact sensors will be placed at the top and bottom of the kneecap to ensure that the sensor is in constant contact with the user’s skin regardless of motion. The two airborne MEMS sensors will be placed on both sides of the kneecap which will allow the sensors to pick up any acoustics that penetrate the air when the knee joint is in motion. The sensors will be placed in mesh pockets on the inside of the sleeve along with some protective foam. There will also be a protective sensor package that will shield the sensors from environmental effects. (Figure 2).

B. Sensor Package

Since sensors with high sensitivity parameters are used to measure the acoustics produced by knee joints, packages
were designed using SolidWorks to protect the sensors and provide better functionality during usage (Figure 3). The sensor packages are made of ABS plastic and can be 3D printed due to the simplicity of the design.

![Figure 3: Sensor package for the piezoelectric sensor (left) and the accelerometer (right)](image)

C. Interface Material
To hear and measure sound, the acoustic waves must propagate through a medium at a certain speed. This creates an acoustic impedance, which determines how well sound waves will travel through a medium. In the equation below, the acoustic impedance \( Z \) is equal to the speed of sound \( c \) multiplied by the medium's density \( p \).

\[
Z = c \times p
\]

In this application, we have two different mediums that need to have similar impedances so that the sound waves can travel through with minimal reflection. The Intensity Reflection Coefficient (IRC) is used to calculate how much of the sound waves will be reflected. This value calculated from the equation below, determines how much sound will successfully penetrate both mediums and enter the sensors.

\[
IRC = \left( \frac{Z_2 - Z_1}{Z_2 + Z_1} \right)^2
\]

While the design of this device aims to ensure maximum contact between the user's skin and the contact sensors, air pockets between the two mediums may be created during use. Air has a very different impedance than skin, which will cause majority of the sound waves to be reflected and not reach the sensors. To solve this potential issue, an interface material is needed to help facilitate sound wave penetration so the sensors can measure the acoustics of the knee joint. For this application, PDMS is the best interface material to use since it has a similar impedance to skin.

III. INTERNAL DESIGN

A. Airborne and Contact Sensors
The piezoelectric contact sensors are used to measure vibrations from the knee joint though the user’s skin. The airborne MEMS sensors are used to measure audible sound from the knee joint that penetrates the air.

![Figure 4: Airborne MEMS (left) and piezoelectric contact (right) sensors](image)

B. Bluetooth Module and ADC
The Analog to Digital Converter (ADC) on the Arduino Uno will transform the voltage outputs of the airborne and contact sensors into digital outputs so that the Bluetooth Module can recognize the data. Wires will connect the sensors to the ADC pins of the Arduino Uno for the conversion of the outputs and connect the ADC output pins to the input pins of the Bluetooth Module Evaluation Board.

![Figure 5: Wire configuration for sensors connected to the ADC which is connected to the Bluetooth Module for connectivity to the user’s phone.](image)

IV. RESULTS

![Figure 6: Proof of functionality for Airborne MEMS Sensors](image)

V. CONCLUSION

A smart knee brace was designed to continuously monitor the progression of knee joint health. The knee brace design consists of a compression sleeve with design modifications to protect the electrical components from potential environmental or situational hazards and secure the components to ensure the user’s safety while the brace is in use. The device includes contact and airborne sensors that measure the acoustics produced by the knee joint that can be analyzed to determine knee joint health. An ADC and Bluetooth Module are also implemented in the design to allow the user to access their data from their phone or computer through Bluetooth technology.

ACKNOWLEDGMENTS

We would like to recognize the College of Engineering and Engineering Technology at Northern Illinois University for providing the funding and tools necessary to make our project possible. We would also like to thank Dr. Moghimi and Sandhya Chapagain for their intellect, guidance, and access to resources during the development of this project. Thank you for your continuous support.

REFERENCES

Abstract: Our mission is to design and build a force platform apparatus capable of linear movement. It shall be closely synchronized with a virtual environment viewed by the subject for the purposes of measuring physical response. The apparatus will be useful in the fields of physical therapy, training, and research within the biomechanical field. The moving platform would allow researchers to study natural human reactions to perturbations and potential effects of interventions.

I. INTRODUCTION

Over time, humans learn balance innately as we learn to walk. This is a skill we continue to utilize and improve upon without even knowing it. Over the years, balance problems can arise from injury, disease, and aging. The variety of problems and the variety of causes make issues with balance very complex. To fully understand what is happening, it is important to consider different aspects of balance such as the effects of sight and sound.

To put his years of experience in balance and postural control into practice, Dr. Hamid Bateni has begun to make use of a new system. The testing environment consists of a platform apparatus, an Oculus Rift, and a safety harness. Dr. Bateni is utilizing an Oculus Rift VR (Virtual Reality) headset and a computer that meets the specifications required with this operation to simulate an environment for the patient. This simulated environment allows for the ability to control what the patient sees and hears. The platform apparatus is set up in such a way to safely cause perturbation to the balance of the patient standing on top. By making use of the movement and the simulated environment, Dr. Bateni can see and study the effects of multiple senses on the balance of a patient.

The system is set up with a linear pneumatic actuator that is set up to rotate in a full circle allowing the platform to be moved in any desired direction. A camera system is set up to record what is happening so the reactions of the patient can be easily reviewed later. By allowing the platform to move at any angle, data can be compared for various directions. This, with differences in the simulated environment, open the possibility for a vast amount of studies to be conducted. This paper describes how this system was created and how it is beneficial. Without the major cost of many force platforms, and while maintaining a focus on safety, this system serves to greatly aid in balance and postural studies.

II. METHODS

This project was divided into three sections: Platform, Pneumatic Radial Actuation Driver (PRAD), and Virtual Reality Synchronization. Taking into consideration the team was composed of all Mechanical Engineering students, two team members were assigned to work on the electronics of the PRAD.

The PRAD is responsible for rotating and moving the platform at a certain angle, in degrees, inputted by the operator. Once the actuator is moved into position, the actuator will fire and cause the platform to move in a linear direction. The system is controlled by an Arduino microcontroller. The Arduino commands the stepper motor driver to send a certain number of steps to move the motor to a location in degrees between 0-360. The Arduino also controls a relay that is wired into the directional control valves of the linear actuator. The actuator is programmed to have the arm retracted as its “resting position”. It will only be extended after the stepper motor reaches its location. The material Tivar was used for the turntable due to its strong rigid properties to prevent flexing when the test was being conducted.

The platform was reinforced at the corners by welding steel bars at each corner to prevent deformation when an individual would stand on the platform.
III. RESULTS AND DISCUSSION

Many modifications were made to the first-generation prototype. Essentially, the produced prototype was intended to be a proof-of-concept design only and does not meet the minimum requirements in order to be a fully functioning research tool. Further design with an expanded budget was required to achieve such a tool. The new modifications made on the past design set out to advance the following key areas of improvement: safety, reliability, presentation, accuracy and synchronization. Our client wants the project to be safe due to the amount of weight that is being shifted under the patient's feet. To mitigate those concerns, we implemented an emergency stop switch and guard rail that surrounds the perimeter of the platform. The project needs to be reliable because it costs a lot of time and money to bring our client’s patients into his lab to conduct research. To solve this requirement, all the wiring was replaced with better wires to include wire ribbing and to get rid of lose wired being agitated during operation. Additionally, the wire diagram was redesigned to cut out unnecessary components and added two step-down transformers within the PRAD housing. Presenting is important to our client because he wants his patients to trust the device as they stand on it. The addition of vinyl tile to cover the plywood platform and replacement of the PRAD housing with metal. Accuracy in the project is directly correlated to the accuracy of Dr. Bateni’s research. To ensure that the desired angle of actuation is met, dynamic breaking is utilized in the stepper motor. The plywood turntable was replaced with a hard, strong plastic called tivar. Doing so stopped the PRAD from lifting off the ground when actuating at large PSI’s. Lastly, our client desired synchronization between the VR and the project code. The project does not currently implement any measures to satisfy this requirement, however, a third-generation team needs only to achieve that last task to make this prototype a working research tool.

IV. CONCLUSION

The 3D moving platform created is a system with a variety of safety features, as well as the ability to easily be altered to suit the needs of the client. With options to change the movement direction and displays on the VR headset, balance studies can be conducted with many different variables. This setup also allows the data to easily be studied and referenced later due to the camera system. By using strong, but readily available components, this system can be built for a price much less than related systems for purchase. To better understand and treat underlying causes of balance problems, systems like this can help to improve lives.

V. ACKNOWLEDGMENT

We would like to show our appreciation to the faculty who provided technical support across various areas of engineering disciplines. Thank you to Mr. Fahad Alqahtani, your support and time spent grading our work has been immeasurable towards our success. Thank you to Dr. Ting Xia for his support as our advisor, Dr. Ji-Chul Ryu, Mr. Edward Miguel, and Mr. Matthew Kleszynski. Very special thank you to Dr. Hamid Bateni for his support as the project client and bringing the project to life. Lastly, thank you to Northern Illinois University for providing the budget, space to work, equipment, and an abundance of resources needed to complete the project.

VI. REFERENCES


[3] Severini, Giacomo; Straudi, Sofia; Pavarelli, Claudia; Da Roit, Marco; Martinuzzi, Carlotta; Di Marco Pizzongolo, Laura; Basaglia, Nino, “Use of Nintendo Wii Balance Board for posturographic analysis of Multiple Sclerosis patients with minimal balance impairment”, J Neuroeng Rehabilitation, v14; March 2017, (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5346266/)


Short Range Wave Glider
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Abstract—Being able to study our bodies of water is extremely important to understanding our earth and how climate change is affecting it. Robotic, underwater collection devices are being designed and utilized to help with this endeavor. By taking a robot that is traditionally used in an oceanic setting and modifying it to be suited for research in the Great Lakes, a different form of data collection can begin to take place and further increase our knowledge for that region. The Short Range Wave Glider combines the benefits of several different underwater robots and is designed specifically for Great Lakes research.

I. INTRODUCTION

The Great Lakes hold approximately one-fifth of the world’s surface freshwater. They are also the singular home of many animal species, both in the lakes themselves and along their shorelines. [2] This makes them a unique and important ecosystem. However, they are under many different threats, such as pollution, invasive species, and climate change. Pollution can come from runoff, mining operations, and from toxicants that are released into the water. Unfortunately, a minimal amount of water leaves the lakes which causes pollution to build up over time and become a semi-permanent part of the ecosystem. [2] Furthermore, the effects of climate change on the Great Lakes can be devastating. Not only will climate change continue to decrease the quality of the water within them, the changing climate will exacerbate the problem of pollution and invasive species in the lakes. The changing environment within the Great Lakes due to climate change is making the lakes suitable for invasive species. Additionally, the hotter temperatures cause the lakes to recede, causing the wetlands which would normally act to filter pollution from entering the lakes to dry out. [2]

Research must be done throughout the Great Lakes and other large freshwater bodies to understand and counteract the factors that threaten them. By having an autonomous or semi-autonomous system gathering data from around the lake, factors such as, but not limited to, water temperature, air temperature, and water quality could be monitored and recorded. Also, the threat posed by invasive species could be more closely monitored and controlled. On average, a new non-native species is found in the Great Lakes every 28 weeks. [2] By utilizing data gathered at various points throughout them, the populations and movements of these invasive species can be monitored and studied by researchers to control the inflow of non-native species and their overall impact on the ecosystem. By measuring other aspects of the water quality, such as pH level, conductivity, and oxygen level, the effects of pollution on the lakes could be studied. This information would not only be useful from a research standpoint but could also be used by communities surrounding the lake who may be using the lakes’ water for city or agricultural purposes.

Long Range robots, such as the Liquid Robotics Wave Glider, are not necessary for bodies of water like the Great Lakes. The Wave Glider is designed and built to withstand extreme weather and temperatures, as well as be in use for months or even years at a time. Since the freshwater bodies are much smaller and experience much less extreme conditions, using such a robot would be a waste of resources. Unmanned Surface Vehicles themselves are not widely used in the Great Lakes, even for longer range applications, and are unheard of for shorter range applications which are ideal to help supplement currently ongoing research.

II. MATERIALS AND METHODS

The Short Range Wave Glider is comprised of three different areas, electrical, mechanical, and computer science. Each of these areas had to be developed to work seamlessly with each other to create a working robot.

A. Electrical

The Short Range Wave Glider requires several different electrical components to work, the first of which is powering the robot. It is powered using several sets of lithium polymer batteries. These batteries create a network of varying voltages throughout the wave glider that power a variety of sensors, microprocessors, and computers. The second component is comprised of the environmental sensors. These sensors were chosen and placed throughout the robot to be able to detect conditions underwater. This includes detecting water temperatures and aquatic bioacoustics. These sensors will work together to give an indication of the water conditions around the Great Lakes and the correlating animal life. Lastly, a communication and navigation system was developed. This system was created to allow for the wave glider to complete obstacle avoidance, and determine its position, speed and heading all throughout the Lakes. Furthermore, the communication system takes the data that is being collected by the environmental sensors and transfers it to modems that would be available at
different points throughout the lakes, making it so that data could be available to process and study before the Short Range Wave Glider returned from its mission.

B. Mechanical

Mechanically speaking, the Short Range Wave Glider consists of three major components: the float, the submersible, and the tether that will connect the two. The float, which will ride on the surface of the water, is used to house the batteries, a microprocessor, and the computer which will be responsible for reading and storing all the environmental data collected. It is covered to protect the inner components from any water and has two hatches to allow the operator to access the components from maintenance. Wires connecting the sensors in the submersible to the computer and the batteries in the sub will pass through the tether. Finally, the sub will contain the environmental sensors on the Glider, as well as the rudder and thruster system which will be used to steer the entire robot.

![Image](image-url)

Figure 1: Model of finished mechanical design showing float with both hatches open, the connecting tether, and the submersible.

C. Computer Science

Each of the electronic subsystems and sensors had to be coded and integrated. The various sensors are managed by a microcontroller development board which pipes data into a microprocessor development board where the data is managed within a ROS framework. The ROS framework is used to manage all other subsystems. In the ROS framework, the data from the sensors is interpreted and recorded. The interpreted data was used to determine position, heading, and incoming obstacles. All of this information was compared to the predetermined geo-bounded area of operations to determine if alterations to the course were necessary and instructions were sent to modulate the steering mechanisms as needed.

III. RESULTS AND DISCUSSION

The prototype of the Short Range Wave Glider was designed and built to house all the components needed as well as be resistant to the environment found in the Great Lakes. Between the float and the submersible, the wave glider holds the combination of environmental sensors that will be used to create a picture of the health of the Great Lakes regions. Each of the systems was tested individually to prove that it could work together to accomplish the tasks set forth for it. The mechanical aspects of the prototypes were shown to be waterproof for extended periods of time. The environmental sensors gave indication that they could pick up accurate readings and store, send, and process this information. Although, due to the circumstances, the prototype was not able to be tested thoroughly as a comprehensive unit. However, due to drawings in CAD, wiring diagrams, and testing of basic code, it was shown that the Short Range Wave Glider would have been a success underwater data collection device.

IV. CONCLUSIONS

Overall, the prototype of the Short Range Wave Glider was built as a first iteration of an efficient and creative underwater data collection robot that was intended specifically for the Great Lakes. While the manufacturing phase was limited due to unforeseen circumstances, each system of the robot had a proof of concept created and tested. With the success of these tests, it could be concluded that the Short Range Wave Glider would have been proficient in its tasks as a data collection device. Its sturdy and relatively small chassis is an asset to being used within the Great Lakes regions. Furthermore, its combination of environmental sensors helps to create a portrayal of the water conditions around the lakes.

ACKNOWLEDGMENT

We would like to thank our faculty advisor, Dr. Ryu, for his guidance and advice throughout the construction and testing of this project. We would also like to thank Northern Illinois University College of Engineering for the use of its resources in making this project possible. Finally, we would like to thank our various sponsors, Blue Robotics, Sparkfun Electronics, Fischer Connectors, and Aquarian Hydrophones for their generous donations.

REFERENCES


**ABSTRACT** — High levels of carbon dioxide (CO₂) aboard the International Space Station (ISS) have been reported to cause cognitive impairments among its crewmembers. Jet Propulsion Laboratories (JPL) proposed a project to create a wireless carbon dioxide sensor array to measure CO₂ levels in the environment. The network that will be used for this array will be ZigBee. Nodes will be comprised of the CO₂ sensor, an Arduino, and an XBee Transceiver. These nodes will be programmed according to their role as a coordinator, router, or end device. The array will collect and deliver data in real time. The data will be displayed in a Graphical User Interface and will allow crewmembers to monitor and adjust the air quality as needed.

I. INTRODUCTION

The primary use of the International Space Station (ISS) is to allow crewmembers to conduct research and experiments in a zero-gravity environment. There are 10 long term countries associated with the ISS, but other countries have also worked inside the structure. Jet Propulsion Laborites has stated an issue within the International Space Station (ISS) where high levels of carbon dioxide (CO₂) have caused cognitive impairment among its crewmembers. The team has been tasked with designing a wireless carbon dioxide sensor array. This array will output real time data for the crewmembers on the ISS to monitor their environment and adjust the air quality as needed.

Similar work has been done on the ISS to detect the location of crewmembers and measure the temperature and humidity in their environment using an Impulse-Radio Ultra-Wideband network. Although similar, the selected design for the CO₂ array uses a ZigBee network.

Some constraints that will be considered while designing this array are the need for message relaying given the size of the ISS and given the concern that RF signals be absorbed easily due to the material of the ISS, and the concern of the network being able to operate together with the WI-FI network already in place in the ISS. This project will have a positive impact because it will allow the understanding of CO₂ level variations within the ISS and the effect it can have on a person’s cognitive impairment.

II. NETWORK

The selected design for the CO₂ array will use a ZigBee network. ZigBee is a set of communication protocols for low-data-rate wireless networking, particularly suitable for wireless sensor networks [1]. ZigBee was the chosen network for the sensor array because of its mesh capabilities, IEEE security protocol, an overall full network stack, and the availability of ZigBee devices in the market. Zigbee’s mesh network requires three types of nodes: the coordinator, end devices, and routers. Figure 1 illustrates how these nodes interact with each other to make up the network.

Figure 1 Network Setup

The coordinator will collect incoming data from the routers and transmit to the main central processing unit (CPU). The end device will collect data from the CO₂ sensor and transmit that data to the router which relays messages from the end device to the coordinator.
These nodes are connected using a mesh network topology to transmit data between them. A mesh network is a local network topology in which the infrastructure nodes allow for easy expansion because they do not require that all nodes be within reach of the coordinator, allowing as many other nodes as needed to route data to and from clients.

Zigbee also has reliable data transfer. This comes from the network protocol by having the devices create acknowledgements and from a mesh network because all the devices are interconnected. A benefit of nodes being interconnected with each other is that the network can “self-heal.” This is possible because in a mesh topology, data routes are created on demand and have the ability to alter those routes if there is a change in the environment [2], so if one router node fails, the data can be re-routed using a different path.

ZigBee’s expandability, maturity, ability to extend the range of the network by relaying packets, and the full protocol network stack make it a suitable network for this array.

III. DEVICES AND SOFTWARE

Each node is constructed using an Arduino Mega, a shield board, and an XBee S2C transceiver. The Arduino Mega is the microcontroller that will be used to receive the data from the CO₂ sensor and send it to the transceiver. The Xbee transceiver will be installed on top of the Arduino Mega using the shield board.

The programming software that will be used is XCTU. XCTU is designed to allow interaction with ZigBee Pro modules through a simple graphical interface. The program will also allow the management and configuration of RF devices, firmware updates, and create communication with radio devices. XCTU is important for the final purpose of expanding the network through additional devices [3]. The Arduino Mega will be programmed in C language. The C programming language was chosen because it offers functions, loops, arrays, and all other essentials for low-level programming.

The data that is collected will be displayed using a graphical user interface (GUI). Python will be used to program the GUI because it has existing libraries that are strictly chosen for the GUI and due to the syntax, it has easy implementation.

IV. CONCLUSION

Currently, there is no wireless carbon dioxide sensor array integrated into the ISS. This CO₂ sensor array design for Jet Propulsion Laboratory will monitor the carbon dioxide levels in the ISS and distribute the data in real-time. This can help prevent high levels of carbon dioxide which has been reported to cause cognitive impairment and other adverse effects among the crewmembers of the ISS. The implementation of this array will allow the air aboard the ISS to be monitored and adjusted as needed.

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REFERENCES

Model Based Monitoring

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Abstract— Woodward manufactures, distributes, and designs motors that are applied to various industries. For the purpose of this project, the aerospace applications of motors are the focus. The motor lifespan applies to all motors despite differing scenarios. From a financial standpoint, a self-learning system would provide a more accurate understanding of unique motor lifespans in accordance with the servicing environment. The self-learning tool will perform self-corrections to motor behavior to improve longevity. The test stand manufactured is capable of testing motor functionalities while remaining as a closed loop system. Data collected from the motors was used to obtain a baseline that will serve as a control for the acceptable motor behaviors. A MATLAB Simulink simulation will compare and establish a baseline with data collected from a faulted motor. The faults include failures in the stator winding wire and attempt to force the motor to perform the baseline behavior. The safety precautions taken aim to avoid electrical system damages, electrical shocks, and injuries while machining. Communication capabilities between Simulink and the motor controlling software are used to detect faulty stator windings. The deliverable will address some of the financial concerns while maintaining a quality product that Woodward had brought forward.

I. INTRODUCTION

Woodward, Inc. is a company that manufactures and distributes system components for use in “fixed wing and rotorcraft platforms in commercial, business and military aircraft, ground vehicles and other equipment” [1]. For the purpose of this project, the aerospace applications of motors are the focus. The motor lifespan applies to all motors despite differing scenarios. From a financial standpoint, a self-learning system would provide a more accurate understanding of unique motor lifespans in accordance with the servicing environment. The intent is to incorporate a self-learning tool to perform self-corrections to motor behavior to improve longevity for the future of the project. The deliverable will address some of the financial concerns while maintaining a quality product that Woodward had brought forward.

Brushless DC (BLDC) motors were chosen for the project as they are often used in commercial and military aircraft applications. The benefits of using them is their small size to the amount of power they produce, and the wide range of applications they can be applied to [2]. They are also more readily available to manufacture as components are more accessible from a wider range of manufacturers. BLDC motors can contain numerous Hall effect sensors, furthermore motors with three Hall Effect sensors will be the focus. The sensors detect the position of the rotor by sensing the magnetic poles produced by the stator winding wires. Figure 1 depicts the components and where they physically lie.

![Figure 1. Cutaway of a Brushless Motor [3]](image)

The figure closely relates to the motor chosen for the testing purposes [3].

From the three most common failures that Woodward experiences, stator winding faults were chosen to be the first fault type that the project will encounter. Stator winding faults are common but are normally found during manufacturing and validation and rarely occur during operation. Modeling a full short in the stator winding would not serve to be helpful as motors are designed not to operate when there is one. Due to the static nature of the windings within the motor chamber, sensors can be arranged within the motor while the motor is operational without causing unprecedented faults from the testing equipment.

The project considered some of the existing testing methods. A test environment will be created with two motors and supporting components to simulate variable loading and worn stator wires.

II. METHODS AND MATERIALS

A test stand was manufactured with equipment capable of testing motor functionalities while remaining as a closed loop system. The components of the test stand are as follows: a motor controller, microcontroller, sensors, a load motor, motor, and software. The DRV8312-69M-KIT from Texas
Instruments is what the team utilized as the foundation of the project.

The control card included in the kit will perform the role of the motor controller coupled with the paired software. The motor controller will allow for regulations of the inputs to the motors and is a direct connection between the power supply and the motors. The microcontroller role is taken by the Data Acquisition and Control (DAC). DAC boards create a link between a physical system and a computer allowing for communication between the two. For electric motors, a DAC is the primary hardware used for receiving data and controlling motor function with software, algorithms, or models. Thermocouples are the sensors that will be connected to the motor and DAC.

Temperature sensors would be necessary to ensure that there are no additional factors altering the rotary position detection accuracy. Thermocouples are an effective and cheap tool able to detect the temperature changes within the stator winding chamber at various sensitivities. As Hall effect sensors are sensitive to temperature changes and the magnetic field produced by the stator windings, close attention needs to be made to temperature changes.

Load motor and circuit is comprised of a 3-phase BLDC motor, resistors, 3-phase diode bridge rectifier, and switches. The motor coupled with the loading circuit serves as a load for the motor that is monitored. The load motor relates to the 3-phase diode bridge rectifier to convert and direct the current to pass through a series of resistors activated with their corresponding switches. The reason for this is to imitate a fault in a stator winding such as a nick in the wire or even a crack in the insulation. The switches will allow for their to be adjustments in the severity of the simulated nick.

Data collected from the motors without failures or faults will establish a baseline that will serve as a control for acceptable motor behaviors. A MATLAB Simulink simulation will be included in the process in order to compare the incoming data from a faulted motor with the baseline data. By comparing the data sets, Simulink will establish a baseline that will serve as a control for adjustments in the severity of the simulated nick.

From the motor test stand, a basis of design was created to drive the MATLAB Simulink models. The motors were tested with open and closed circuits. Once the closed circuit was completed, the motors were tested with varying resistances based on the open and closed switches, and the data was then logged for comparison to the test simulations completed by the motor models.

The Simulink model for the open circuit showed similar trends in the data measurements taken through the scope tools in Simulink. The closed circuit test setup with the varying resistances was tested on a very basic level on the test stand, so the motor model in Simulink was used for the basis of analysis for failures in windings of the motor. The use of the added resistors helped to mimic leakage of the current and gave a look into the trends of the motor failures seen in stator windings.

IV. DISCUSSION

With the trends analyzed from the motor failure simulations, it has been verified that the leakage of current from the stator windings affects the overall performance of the motor and lifespan of the components. The use of heat detection sensors to detect changes in the temperature of the stator can help to detect these leakages before there is a significant deterioration of the windings, or can detect when there are shorts in the system that cause the failures in the performance of the system.

V. Conclusions

In fruition, Model-based monitoring for 3-phase motors will create a simulation tool to assist in motor failure predictions. Through testing and data acquisition, a MATLAB Simulink program has been created to simulate stator winding faults in BLDC motors. Further work on the system will be able to find trends and operational baselines for the test motors which will help with the identification of impending failures or faults. Being able to identify these faults early would allow for the development of maintenance plans which are more accurate and customizable to the environment that the motors will be serviced in. With this project, Woodward also seeks to improve the accuracies of lifespan calculations for in-service motors across a variety of actuators that they design and manufacture.

ACKNOWLEDGMENT

The Woodward team offered their full support by driving to NIU most weeks to attend the weekly meeting, transporting the team’s equipment, and communicating with the team the entire duration of the project. The Woodward team has a remarkable group of individuals.

Dr. Zinger also made his lab time open for the team to ask questions about varying equipment, potential designs, and the preexisting testing stands in the lab.

REFERENCES

Visualizing Stress Fields With Photoelasticity Under Multiaxial Loading

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Abstract—The stress developed in a component due to external loading is one of the most important criteria for engineers to understand as stress governs material failure. However, the internal stress distribution/field is often difficult to visualize. In order to impart a better understanding of stress to students and visualize these distributions for research purposes, Dr. Sinko has requested the design of a multiaxial loading device that uses photoelasticity to visualize stress fields developed in transparent samples via a polariscope. This device should show the stress field of any clear sample subject to compressive, tensile, torsional, and/or bending loads. In this work, a loading frame is designed that holds a transparent sample and applies all loading conditions through the use of a linear actuator and two stepper motors. Further, a control system is developed that allows for user input from a command-line interface for specification of loads and displacements.

Keywords—Photoelasticity; stress; distributions

I. INTRODUCTION – PHOTOLELASTICITY

Students enrolled in mechanical engineering programs must take mechanics of materials classes as part of their core curriculum. In this class, students learn about the stresses and strains that form within materials under load. While the stresses and strains are understood through equations and definitions, it can still be difficult to fully understand these concepts without being able to visualize how these quantities varying internally within the materials.

One method of visualizing stress is through the use of photoelastic behavior of transparent materials. The photoelastic effect is the rotation of the polarized light by the stress field in the material generates a pattern displaying contours of equal stress [3]. In other words, as the stress distribution in the material changes, the visual patterns observed when looking through the sample will also change and can be used to show the stress distributions.

Normal light occurs as waves that will disperse within a clear object and no patterns will be seen. When light is polarized, however, the waves that make up the light are restricted to a single plane [2]. The light in the photoelasticity device is provided by an array of LEDs. The light shines through a polarization filter, the demonstration sample, then another polarized filter rotated 90° from the first filter. This orientation allows the light to display the stress distributions for demonstration.

If the light shining through a clear object is polarized, the light will change based on the stresses that are distributed within the clear object due to a change in the refractive index of the material predicted by the photoelastic effect. Put more simply, different values of internal stress correspond to the different colors of visible light as the stressed areas will act similarly to a prism and separate the colors. As shown in Figure 2, this provides a mechanism for visualizing stress distributions and point of stress concentration in the material.

II. DESIGN REQUIREMENTS

The objective for the project was to create a loading device that can view the stress fields in test sample using photoelasticity. The project needed to be able to apply up to 3 types of loading at a single time with loads ranging from 0 Newtons to 100 Newtons. The user should be able to control the applied forces by giving the system the forces or the desired strain on the sample and some size and material properties of the sample. The device also needed to be able to be moved easily so that it can go in and out of classrooms without extra equipment to move it.

III. STRUCTURAL DESIGN

To demonstrate how stress fields change under different loading conditions, a structural frame was developed that was capable of supporting the sample and provides three primary
types of loading: torsion, axial loading (tension and compression), and bending. The overall design of the device is pictured in Figure 3.

![Figure 3: Isometric view of Photoelasticity device](image)

**A. Torsion**

To apply torsional loading (i.e. twisting) to the sample, the top clamp is held fixed while the bottom clamp is rotated. This is accomplished by mounting the bottom clamp to a gear that rotates on a pin and is clipped into place. The gear is turned by using a stepper motor and another gear to produce the required torsional load. This configuration allows the motor to be positioned away from any axial loading that can be applied concurrently.

**B. Axial Loading (Tension/Compression)**

Tensile and compressive loading of the sample fall under the same system where the sample will either be stretched or compressed. Axial loading is accomplished through a rack and pinion system driven by a stepper motor. This is the selected method over a discrete linear actuator as it is more rigid and can better withstand forces from other axes. The discrete motion of the stepper motor provides an accurate representation of the amount of displacement caused in the specimens, allowing the load to be more closely controlled.

**C. Bending Moment**

Bending of the sample is accomplished by applying a transverse point load which causes a bending moment to develop throughout the sample. The point force is applied using a linear actuator. It is mounted so that it can be moved up and down the frame to set the position at which the force can be applied and thereby change the bending characteristics of the beam.

**IV. CONTROL SYSTEM**

Software running on a Raspberry Pi controls the loading mechanism’s actuators through the Raspberry Pi’s general-purpose input/output interface. The loads applied to the specimens are user-specified. The values are entered through a typical keyboard and monitor interface. Once a load has been specified, the actuators remain active until the specified load has been applied. The system will hold the loading state until the user specifies that the system should reset, then all loads on the specimen will revert back to default (zero). Since this system does not rely on sensor feedback, the actual applied load is approximate with regards to the user-specified load. The software calculates the necessary displacement for a specified load in the case of torsional and axial loading. However, a specific load can be applied with the linear actuator by supplying specific currents. A logic diagram for the developed software is shown in Figure 4.

![Figure 4: Logic Diagram for the Control System](image)

**V. DISCUSSION**

Understanding stress is vital to any mechanical engineering student. We were able to successfully create a prototype to display stress for students to benefit from in their studies.

![Figure 5: Prototype Photoelasticity device](image)

**ACKNOWLEDGMENT**

We would like to thank Dr. Sinko for his guidance throughout this project. We would also like to thank PM Mold Inc. for allowing us to use their equipment.

**REFERENCES**


Smart Handicap Accessible Storage Unit

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Abstract—Physically disabled people who require the use of a wheelchair have a limited range of mobility that greatly reduces their ability to access conventional storage solutions. This often limits their independence which may lead to reliance on other people to help with basic everyday activities. The Smart Handicap Accessible Storage Unit is an affordable home automation system that seeks to improve the lives of physically disabled users. The standalone unit provides an automated shelf retrieval system that can be implemented without modifying existing spaces. Complete mobile control over the system will allow the user to operate it safely from whatever position best suits their needs.

I. INTRODUCTION

Physical disabilities can greatly limit a person’s ability to perform many tasks in daily life. The Americans with Disabilities Act (ADA) is a law which mandates that public places, businesses, schools, and many other places are accommodating individuals with disabilities [1]. ADA Section 308 outlines the ranges that one can be expected to reach, however, most traditional places of storage do not fall within these ranges, making them inaccessible for handicapped individuals. The Smart Handicap Accessible Storage Unit seeks to provide accessible storage for those with limited mobility at an affordable price. The ability to access storage in more areas will help the user to live more independently and increase their quality of life. The concept of automated storage and retrieval systems is not new technology. However, current products are generally not suited for home users due to their scale, complexity, and substantial cost. The Smart Handicap Accessible Storage Unit takes advantage of a modular cabinet system and new wireless control technology to create a unique storage unit that is highly customizable and affordable.

II. PROJECT DESIGN

The single shelf lift concept was chosen as the optimal design for the Handicap Accessible Storage Unit. Many factors were considered in this decision including cost, effectiveness, suitability for home use, safety, and difficulty of implementation. The single shelf lift design decreases cost and complexity which increases the overall efficiency of the storage solution. The design is fundamentally different than the other alternative designs and products that are currently available. Rather than moving the entire cabinet to an accessible place, this system only transfers the desired item, minimizing the amount of work required and allowing a standard power source to be used.

III. COMPONENTS

A. Vertical Drive System

Safely and efficiently transferring a storage load vertically requires a robust mechanical design. A high-strength aluminum extrusion was chosen to provide the main framework inside the cabinet. Precision high-load linear rails were chosen to guide the system which is driven by a twenty-degree rack and pinion system. Power to the rack and pinion is provided by two 425 oz-in position control stepper motors for optimal torque to carry the maximum load.

B. Horizontal Exchange System

The horizontal shelf exchange mechanism provides the ability to remove bins from their storage position so that they can be transferred to the accessible position. The exchange mechanism uses two precision linear rails with rack and pinion gearing to provide linear motion. Power to the rack and pinion is provided by a 270 oz-in position control stepper motor to reliably position the shelves. The unique cantilevered exchange mechanism is shown in Fig. 1.

![Fig. 1. Horizontal shelf exchange mechanism](image-url)

C. Safety Measures

Ensuring the user’s safety is a critical component of the unit. Multiple safety measures were incorporated into the design to prevent causing a dangerous situation for the user. The most outright concern in the design of the Smart Handicap Accessible Storage Unit is suspending a loaded
shelf over the user. Infrared sensors will be used to determine if anyone or anything is in the area under the moving unit. If the sensors line of sight is interrupted, the unit control will prevent operation of the system. These sensors are usually called through beam sensors and will send a signal back to the motor control of the unit if there is any break in the sensor’s line of sight. Additional mechanical measures are in place to prevent a control failure to prevent user injury or damage to the unit.

D. Unit Controls

An internet of things (IOT) application called Blynk was chosen for its reliability and customization capabilities [2]. The application sets buttons as virtual pins that will send logic signals to a Raspberry Pi via a Wi-Fi connection. Once a user selects a function the virtual pin will be set to high logic providing an input to the system. The reason for an application was to reduce the physical connections to the device and provide the user more accessible control options. Logic signals will be processed by a python code in the Raspberry pi and sent to an Arduino Nano via USB serial connection. The Arduino Nano will take the input and run the desired function the user selected.

IV. Prototype

![Fig. 2 Completed prototype](image)

V. Testing and Evaluation

Once the unit was in the final stages of completion testing could begin. Testing of the unit provided comprehensive data showing the cycle time and the units load capabilities. Testing the unit involved applying a load to a desired shelf and running a full cycle. Each cycle was timed at each load to ensure consistent operation during different circumstances. To ensure accuracy the applied load was weighed before and after each test to account for any possible measurement errors. The results of cycle time and load tests showed the unit can reliably function at the anticipated load of 20lbs or 9Kg. Each cycle is completed at approximately 33 seconds.

To test the functionality of the integrated infrared safety sensors during each cycle an object was placed in front of the unit. This was to simulate a person or child that traveled below the shelf exchanger. The results of this test provided the needed verification the unit will stop and pause if the sensors were to be blocked. Once the object was removed the unit continued to function as normal.

VI. Conclusion

The Smart Handicap Accessible Storage Unit provides easily accessible storage for those with physical disabilities. Designing the unit around a modular cabinet system provides a competitive advantage compared to other available solutions. Furthermore, implementation of Internet of Things technology to control the system greatly increases its simplicity and versatility. Complete development and testing of the Smart Handicap Accessible Storage Unit was accomplished during the Senior Design process. A fully functional and safe prototype was produced which met the original design objectives of developing a highly versatile and accessible system. Extensive evaluation and analysis of the system validated its safety and proved the system to be a viable solution. Although the unit was not evaluated by an actual handicapped user, thorough testing showed that the system is capable of consistently placing the desired storage bins at an ADA compliant height, while never creating a hazard for the user.

ACKNOWLEDGMENT

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REFERENCES


Detection of Unauthorized Transmissions in a Frequency Spectrum Using Wireless Sensor Network

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Abstract—In the dawn of innovation in which technology interconnects the machine and user to more intentional levels than ever before, security of this newfound technology must be harnessed in order to ensure confidentiality of the consumer’s information in addition to the protection of device performance. A transmitter could be used to maliciously emit an unauthorized signal in order to gain access to sensitive information or control over a device. In order to prevent this, a wireless detector could be implemented to warn a user of malicious activity. The designed detector is comprised of a mesh network of multiple sensors that monitor a frequency spectrum. When an unauthorized signal is detected, the user must be alerted. Each sensor is comprised of a software-defined radio (SDR) which monitors the frequency spectrum and a XBee device that utilizes the Zigbee communication protocol to communicate with the other sensors in the network. The information collected from each sensor is received by the fusion center which alerts the user of a detection of an unauthorized transmission.

I. INTRODUCTION

The evolution of autonomous technology is increasing exponentially which increases the amount of wireless communication and activity among devices and the world around them. It is now difficult to locate any modern-day operation that does not incorporate the use of these devices. A disadvantage to the growth of autonomous technology is the unpredictable methods of attack that organizations or individuals can present to various communities. One form of attack may be to tamper with the communication of these devices that can result in overtaking the device or sensitive information becoming compromised [1]. The consequence of a device being hijacked has its own serious possibilities that can lead to damage to the device, infrastructure, and civilians. Prevention of these situations are to begin in the future in order to maintain the same pace of the expanding world of new technology. The proposal introduces a wireless sensor network that detects unauthorized transmissions in a frequency spectrum. Due to Federal Communications Commission (FCC) ordinances, the design was limited to the FM frequency band; however, the design is a proof of concept assuming the system will behave similarly in more relevant frequency bands like the GPS frequency band.

II. OBJECTIVE

The proposed project design consists of a network of distributed SDR receivers that jointly detect unauthorized transmissions in a frequency band. The receivers are accompanied by a Raspberry Pi, XBee module, and a power source. A combination of each of these components create one sensor within the distributed wireless network. For the communication between these sensors, the functionalities of a Zigbee network is used. The sensors transfer information to the controller of the wireless sensor network which is the coordinator. The coordinator is responsible for maintaining the network and is used to adjust the routing pathway of each sensor. Information processed by the coordinator is then combined using data fusion. Once the collected data is combined, the measurements are combined into a decision statistic which is compared against a threshold. The threshold is specifically important due to the possibility of variant noise in the surroundings. The determined threshold decides whether there are unauthorized transmissions within the area while maintaining a low probability of false alarm. After the detector decides, the information is transferred into a program that displays the location of each sensor, strength of the unauthorized transmissions, average power calculated, and a frequency spectrum indicating the unauthorized transmissions. The application of the project operates in a periodic fashion, monitoring the frequency spectrum continuously.

III. SENSORS

A sensor must be able to receive FM signals from frequency ranges that are allowed by FCC laws. Because the project is aimed to prevent hackers from interfering with certain devices, the unauthorized transmissions are expected to have low power. The receivers chosen have capabilities to monitor frequency bands and detect any low power signal. The receivers collect raw data samples from the specific frequency range and is companied by a minicomputer for the computing. The minicomputer most appropriate for the operations of the project is the Raspberry Pi 3 because of its compact physical form and low price. The data from the receivers is transferred to the connected Raspberry Pi for processing which includes the preparation for wireless communication. The Raspberry Pi is connected to a power supply which allows the other devices connected to operate in a wireless fashion. The XBee 3 modules are also apart of
the design to actualize the mesh capability of the network. The general layout of the sensor can be seen in Figure 1.

![Sensor Components](image1)

**IV. ZIGBEE NETWORK**

The wireless sensor network consists of 10 sensors distributed around an area that utilizes the Zigbee networking protocols for sending the collected information. The Zigbee networking was preferred over Bluetooth because of its mesh functionality and data relaying feature. In order to use the protocols within a Zigbee network, each sensor contains a XBee radio module. Both the Zigbee network and XBee modules use the IEEE 802.15.4 networking protocols for fast peer-to-peer networking [2]. The entirety of the distributed 10 sensors creates a wireless sensor network.

![Zigbee Network Topology](image2)

**V. DATA FUSION**

Among the 10 sensors within the Zigbee Network, a chosen sensor behaves as the coordinator. The coordinator is located at the base station of the wireless sensor network and is connected to a computer. The operation of the coordinator is responsible for selecting the channel, PAN ID, and adjusting other components of the network. The coordinator collects the data gathered by each receiver and then transfers that information into a fusion center.

**VI. DETECTION**

After data fusion is completed, the processed data is then evaluated by a detector. The detector decides if there are unauthorized transmissions in the area. The design of the detector is constructed in Python and requires an established threshold that can keep the probability of false alarm below a maximum specified level. Clustering sensors also gives more accuracy to the detection. The threshold is based on the power within the frequency band. Detection of the unauthorized transmissions occurs when the data processed by the Python code determines that the combination of measurements is above the threshold. The program to simulate the important locations within the project is to be constantly running on an external monitor. If the detector indicates any unauthorized transmissions, the program will then update the user on the essential information.

A graphical user interface like Figure 3 is created to display the results of the project. The position of each sensor is displayed on a generated map of the defined area. When there are unauthorized transmissions detected, the program displays an alert on the map to indicate the location of the unauthorized device transmitting. The program also displays the power of the unauthorized transmissions in dB on the map.

![Graphic User Interface Preview](image3)

**VII. CONCLUSION**

The designed wireless sensor successfully detected unauthorized transmissions. The wireless sensor network may be the next wide-scale project that could be dispatched to increase the safety and the reliability of wireless and autonomous systems. Research conducted for similar products concluded that there are currently limited implementation methods for this type of security. The application of the project is approached in a fashion to allow flexibility to the user while bearing a relatively low price.

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**REFERENCE**


Development of a Body Weight Support System Used for Gait Training (Part II)

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Abstract—Dr. Hamid Bateni has a particular research interest in studying the gait and posture of patients with limited mobility, but a lack of equipment hindered his ability to conduct the necessary gait training studies. A device that would allow patients to therapeutically learn how to walk with an efficient gait under partial weight bearing conditions was needed. Previous studies found that partial weight bearing during gait training provides patients with a better likelihood to learn an efficient gait [1]. This project developed a gait training system prototype consisting of two subsystems: a horizontal position system and a vertical support system. These subsystems, in conjunction with their own sensors and control systems allow the prototype to follow the patient overhead while providing a constant amount of vertical support on the patient. A digital display also allows researchers to change important parameters during the study, as well as, immediately see the results of their studies. Additionally, several safety measures were implemented into the design of the prototype as patient safety is of the utmost importance in the clinical setting in which the prototype will operate.

I. INTRODUCTION

There are several different gait training systems already on the market with the capability of providing partial weight bearing, however, these systems often cost several thousands of dollars. The prototype created aimed to provide similar capabilities of existing systems while remaining sufficiently more cost efficient. To provide a patient with both a beneficial and safe gait training session, the device must follow the patient overhead as they walk while providing a constant vertical support. To accomplish this, the prototype has a subsystems dedicated to each of these tasks. Each subsystem has its own sensor and control system to sense the current state of the system, process the information provided by the sensors, and actuate the subsystem. The horizontal position subsystem uses a potentiometer connected via swivel rod to the plate overhead of the patient to detect the angle of tilt of this plate. This information is then used to actuate a stepper motor which drives the trolley along the I-Beam to keep the system directly overhead of the patient. The vertical support subsystem utilizes a load cell to measure the force experienced by the patient and its feedback controls the vertical movement of the pneumatic cylinder. The pneumatic cylinder moves either up or down to counter the patient’s change in center of gravity during their gait, in order to maintain a constant tension in the cable attached to the patient.

II. METHODS

The horizontal position subsystem must enable the system to follow the patient overhead while minimizing the amount of haptic feedback experienced by the patient. Previous prototypes used sensors that only had an “on” or “off” signal, thus making quick, dynamic responses to patient movement not possible. This prototype used a potentiometer connected via swivel rod to the plate attached to the patient overhead to measure the angle of tilt of this plate. Tilting of the plate indicates patient movement and the potentiometer sends a signal to the control system. The Arduino-based control system actuates the subsystem by driving a motor shaft that rotates a winch, causing the cables wrapped around the two winches to move horizontally along the I-Beam. A trolley on the I-Beam, in which the entire system is mounted to, is pushed or pulled via these cables to match the motion of the patient. Using the angle of tilt of the plate, rather than, an “on” or “off” signal makes dynamic response possible. This enables the trolley to not only move in the same direction as the patient, but move at the same speed as the patient as the trolley’s speed is proportional to the magnitude of the angle of tilt.

The vertical support subsystem must maintain a constant vertical support load on the patient as they walk. For the vertical support on the patient to be constant, the subsystem must be able to dynamically respond to the changes in a person’s center of gravity (COG) during the gait cycle.

The prototype measures the bodyweight of a patient using a load cell attached to the harness of the patient that relays its signal to the control system. The control system then actuates the pneumatic cylinder by opening one of the two solenoid valves causing the rod of the pneumatic cylinder to either retract or extend. When a solenoid valve is opened, air is released from the upper or lower chamber causing that chamber to depressurize. This depressurization moves the “piston” rod in its direction thus retracting or extending the rod to change the amount of vertical support on the patient. The rod of the pneumatic cylinder would retract when the patient’s COG rises and extend when the patient’s COG moves downward. This is
necessary as the load cell will measure a lower value when the person’s COG rises then when the person is standing still.

A third Arduino-based control system allows for the researcher to interact with the prototype in real-time using a digital display. The researcher can change the amount of vertical support on the patient using this interface. The amount of vertical support is also plotted over the duration of that gait training session and can be used to verify that the vertical support experienced by the patient is both consistent and constant.

III. RESULTS AND DISCUSSION

Many modifications to this project had to be made in order to produce a functioning prototype within the time and budget constraints. Essentially, the produced prototype is intended to be a proof-of-concept design only and does not meet the minimum requirements in order to be a fully functioning research tool. Further design with an expanded budget is required in order to achieve such a goal. However, our design does exhibit the functionality of the initial goal.

Initially, planned prototype testing involved operating the prototype on a gantry crane while providing partial weight bearing to a person during gait training, however, access to the lab was not possible due to recent events. Instead, the goal of testing centered toward proof of concept by operating the prototype on a 4’ x 5’ I-Beam using weighted object such as a 25 lb. plate.

The vertical support subsystem was tested by hanging objects of different weights from the system and analyzing the graph of the vertical support on the object over the time of the study.

![Plot of the Vertical Support Provided vs. Time for Various Weighted Objects](image)

The center of gravity of these objects is constant, so theoretically a horizontal line across the plot would indicate a constant and consistent vertical support was provided by the prototype during the trial. Actual testing showed a plot with slight fluctuations from a straight horizontal line, but most fluctuations fell within the threshold of 1 lb. Only being able to test lighter objects on a much shorter I-Beam made proper calibration of the vertical support subsystem very difficult, however, it can be reasonably inferred that the prototype operated with an accuracy within the threshold specified by Dr. Hamid Bateni.

Testing of the horizontal position subsystem proved inconclusive as the wooden I-Beam did not allow for enough horizontal displacement to properly test the subsystem’s response to the motion of the patient. Had the full gantry crane been available for testing, a patient under partial weight bearing would have been used to measure how long it took the subsystem to “correct” itself so that the plate was once again vertical overhead of the patient. Preliminary testing on the wooden I-Beam show promising results as the horizontal position system adjusted quicker and at higher speeds when the angle of tilt of the plate was increased, however, it would be premature to declare that this indicated that the haptic feedback experienced by an actual patient would be minimal when using the prototype.

IV. CONCLUSION

The prototype has the ability to dynamically adjust itself to maintain a constant vertical support as the center of gravity changes during the gait of the patient. It achieves this while showing promise in its ability to minimize the haptic feedback experienced by patients. Limited testing prevented of conclusively determining the prototype’s performance as similar to other products on the market. However, the project was able to create a proof of concept design for the prototype at much lower cost to these similar products.

V. ACKNOWLEDGMENTS

The team would like to thank Dr. Hamid Bateni, Dr. Ting Xia, Fahad Alqahtani, and Dr. Edward Miguel for their assistance throughout the duration of the project.

VI. REFERENCES

SpellVision: A Computer Vision System for the Translation of American Sign Language Fingerspelling to Text

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Abstract—The present project serves to design and build a computer vision system called SpellVision that recognizes American Sign Language (ASL) fingerspelling in real time and displays text on a screen. The ultimate goal is to develop a technology that makes two-way communication more accessible between the hearing and Deaf communities. The project consists of three phases. First, videos of ASL fingerspelling were captured and individual ASL fingerspelling letters were identified using visual inspection. A neural network using the long short-term memory architecture were then designed and trained to identify fingerspelling using the video dataset. Finally, the neural networks were validated by testing its ability in identifying fingerspelling letters from video clips not seen before by the network.

Keywords—American Sign Language; LSTM; Neural Network; sign recognition; feature detector

I. INTRODUCTION

Today, there are an estimated half a million people in the US who use American Sign Language (ASL) as their primary communication method [1] while there are only around 1400 members of the Registry of Interpreters of the Deaf (RID) [2]. There is a clear need for ASL translation to be more readily available so that members of the Deaf Community can have the same opportunities as and convenience as others.

ASL is a full and complete language with its own vocabulary, grammatical structure and culture. The complexity of the language and the people who use it need to be respected. As this project seeks to begin creating a bridge connecting the hearing and Deaf communities it is crucial to remember that full communication is two way. The technology created should not neglect the desires and needs of either party. This bridge should be built meeting in the middle making sure that accommodation is given equally.

The vision for a full, real time, two-way communication platform between signer and speaker is no small task. The intended product of this project, SpellVision is to be the first step towards this larger goal. It set out to create a prototype that can recognize and convert live fingerspelling into text.

II. DESIGN APPROACH

This project takes on a new design approach to the problem at hand. Traditionally, sign language translation devices have required Deaf users to wear or carry excessive hardware. As outlined above, this causes ethical issues by subjecting solely a Deaf user to equip themselves extra hardware in order to accommodate a hearing person [3]. This project adopts a computer vision-based approach utilizing the power and versatility of neural networks for the recognition and conversion of ASL fingerspelling in video to corresponding English letters.

The present product, called SpellVision, is intended for faster, more nuanced fingerspelling like in live conversations. Its design approach adopted the architecture of DeepSign[4], a computer vision algorithm that was designed to recognize full body signing by using a combination of edge detection in images, a self-training image feature encoder and an long short-term memory (LSTM) neural network. Other approaches look at the static form of each letter, whereas DeepSign uses the dynamics of each sign to help predict each letter. Therefore, the LSTM neural network in SpellVision will be trained using many short clips of letters as they form into their recognized shape.

As shown in Fig. 1, the process starts off capturing a video clip of a person signing a letter. The video clip can range from only a few frames to more than 40 frames. Edge detection is performed on the clip and is then passed to an encoder. The encoder vectorizes each image in the clip, and then passes those vectors to the LSTM sign identification network. Once a sign is identified, it is displayed on the screen as text.

III. FEATURES

A. A New Kind of Fingerspelling Dataset

To train the neural networks in SpellVision, a dataset consisting of short video clips has been created by visually inspecting and cutting video of volunteers fingerspelling a set
of words. The SpellVision dataset consists of over 3,000 uniquely dynamic signs of the 26 letters of the ASL fingerspelling alphabet (Fig. 2). To account for both right and left-handed individuals, each clip is also flipped horizontally, for a total of over 6,000 categorized letter samples.

![Image](image.png)

**Figure 2: Distribution of letter clips in dataset**

In order to simplify the data, edge detection was performed on each video clip before insertion into the network for training. This gets rid of unnecessary components such as color shading and allows the network to focus on the movement of the shape alone over time.

**B. A Feature Detector**

Because the Long Short-Term Memory network needs a vector of data representing each video clip as an input, a feature detector is needed to compose each frame of the video to a vector, while retaining the important parts of the video. A sequence is then made up with each video frame’s vector and can then be passed into the LSTM as one object for each full video clip. The feature detector locates all the important features within each frame of the video for the LSTM to then use to classify each video as it is read in.

**C. A Memory Network for Classification**

The final step in the process is passing the encoded signs through the LSTM network for classification. The network is trained with a portion of the dataset and then tested with the remainder of the dataset. At each step in the training and testing process, the network verifies the accuracy of each sign and its corresponding label. After training and testing of the LSTM are completed, any new signs are encoded and then passed through the LSTM which outputs an associated letter and probability of that letter being correct.

**D. Results**

The LSTM network was able to successfully train on the SpellVision video dataset. Training was stopped at 30 epochs to avoid overfitting. When passed a video clip of a single letter being signed, SpellVision is able to correctly identify signs with an accuracy of about 60%. Letters that are consistently identified are of more unique shape, while letters that get confused are of similar shape. For example, letters such as J, L, I, R, and W are identified accurately. However, E, M, N, S, and T can be confused with one another, as the hand must form a fist-type shape to form each letter.

**IV. CONCLUSION**

**A. Discussion**

It was seen that signs with similar hand shapes were often confused for each other. This may point to a deficiency in the chosen feature detector. The vector fed to the LSTM may not contain the specific information needed for consistent recognition of the confused signs. Despite the low network accuracy, it was seen that the LSTM could recognize signs and like hand shapes. This shows promise for the network with future development of the autoencoder.

The results demonstrate that not only can the network recognize hand shapes, but it can identify signs that are changing with time. The use of an LSTM is a novel approach to fingerspelling, and our design proves this concept.

**B. Future Work**

There is still a long way to go to reach a full, two-way, real time communication platform. Improvements need to be made in the accuracy of the SpellVision network. Real time hand detection needs to be developed and incorporated. These steps to improve the SpellVision project are still just the beginning to a future with computer vision ASL translation. One component that has yet to be fully developed is the hand detection network [5]. This has been attempted throughout this project; however, results were not good enough to implement into the rest of the algorithm. In addition, the algorithm still needs to be integrated into a device equipped with a camera so that the real-time, real-world performance of the system can be evaluated.

**ACKNOWLEDGMENT**

The group thanks our faculty mentor, Dr. Ting Xia and TA, German Ibarra for their support and guidance though this project. The group also thanks Dr. Robert Sinko for providing computing hardware for network training, and all the volunteers that helped film our data set. The group also thanks the executive board of the NIU Deaf Pride Club for their advertising support.

**REFERENCES**

[1] American Sign Language Program @ The University of Iowa (Department of Speech Pathology and Audiology, 2004) ASLTA (NC ASLTA and NCAD Ad Hoc Committee, 2004) Colorado Department of Human Services (Colorado Commission for the Deaf and Hard of Hearing, n.d.)


Abstract—With an aging population comes an increased need for advanced rehabilitation. Modern technological advances in the field of robotics are paving the way for high-tech yet cost-efficient biomedical devices. Exoskeletons allow for the rehabilitation of the neuropathways as well as an increased ability in motor function. The fourth-generation design of the robotic exoskeleton for neuromuscular rehabilitation and exercise is the embodiment of this idea. Using the information provided by the three previous generations, as well as the understanding granted from studying other designs and patents, an easy-to-use and sustainable rehabilitation device comes to fruition. (Abstract)

Keywords-component; formatting; style; styling; insert (keywords)

I. INTRODUCTION (HEADING 1)

A stroke is defined as a massive blockage of blood flow to the brain, causing immediate death of brain cells. Approximately 800,000 Americans suffer from a stroke each year. This trauma can cause long-term disability and often leads to death. [1]

Following a stroke, survivors often suffer from both physical and mental ailments. While many of these issues can be treated with rest or medicine, physical aftereffects require prolonged rehabilitation. Physical conditions common among stroke survivors include weakness, paralysis, and inattention to one or both sides of the body. [2] The exoskeleton aims to combat these issues on all fronts. The movement of the exoskeleton rebuilds the neuromuscular pathways in the brain and provides stimulation to the affected muscles.

With an increase in the number of stroke patients comes the need for a more efficient method of rehabilitation. This project involves the redesign and enhancement of an exoskeleton used for rehabilitation and exercise. The purpose of this project is to design an external apparatus to assist patients with neuromotor impairments as they progress through their rehabilitation. In order to accomplish this rehabilitation, the device utilizes a master-slave setup. When a user flexes and extends the forearm on their side unaffected by stroke, the motor on the other extremity actuates. This mirroring allows the brain to rebuild neural pathways previously diminished by stroke and regain lost functionality. This device provides aid in the restoration of a patient's mobility and strength, allowing patients to perform movements consistently and predictably, while accurately tracking their progress. The use of robotics creates a system that is efficient, sustainable, and cost-effective.

II. DESIGN

A. Design Overview

Stroke rehabilitation is usually confined to a rehabilitation clinic, and the necessary equipment cannot be transported to a patient’s home. These limitations cause rehabilitation to take a lot of time and are often accompanied by a large out-of-pocket cost. Each year, stroke rehabilitation costs the United States an average of 32 million dollars. [1]

This design aims to provide independence and ease to the user as they progress through their rehabilitation, without adding the extra burden of cost.

B. Components

The key features of the design include the frame, the circuitry, and the control system.

The frame of the exoskeleton includes two arm braces, each configured to fit either the left or right arm of the user. The mechanical components of the frame are manufactured out of aluminum. Aluminum is strong yet lightweight and can be processed at a minimal cost. Each frame is situated on the outside of the arm, with upper arm and forearm supports connected by a joint at the elbow. The frame is a two-bar linkage with adjustable cuffs, a housing unit on the back of the upper arm, and hand supports. The adjustable cuffs allow for the device to be used on patients of varying sizes. The components of the frame can be seen in Fig. 1.
using an Arduino Uno microcontroller and the Arduino Integrated Development Environment (IDE). The Arduino ATmega328P boasts high-performance capabilities while remaining compact and inexpensive. Two separate power supplies are used to supply power to either the control system or the motor. The motor driver feeds directions to the motor from the microcontroller, allowing for movement. The circuit schematic is displayed in Fig. 2. Because the exoskeleton is designed to service both sides of the body, two of each component are included in the circuit. Included in each side of the circuit is an Arduino Uno R3 with an ATmega328P microcontroller chip, a 12-bit capacitive modular encoder, a DC gear motor, a Pololu motor driver carrier, and the logic and motor power supplies.

C. Operation

The operation of the device relies on user input. The exoskeleton has two settings. The first setting is a master-slave configuration designed for patients with decreased ability in only one side of their body. The fully functioning arm acts as the master while the arm with a decreased ability acts as the slave. The user moves the master arm, triggering a similar movement in the slave arm.

In the second setting, the user can control the speed and direction of the movement using buttons placed near the handgrips. The speed and direction designations are programmed into the Arduino using pulse width modulation (PWM) and the 12-bit encoder.

D. Artistic Integration

Deviating from the three previous generations of the exoskeleton, the expertise of an art student was used to ensure a sleek and ergonomic design.

III. EXPERIMENTATION AND RESULTS

The physical exoskeleton was tested to ensure that the design would not break during use. Mesh testing was done using Ansys software, resulting in stress concentration and displacement analyses. The results of these tests are displayed in Fig. 3.

IV. CONCLUSION

The purpose of this design is to aid in the rehabilitation of stroke patients. Using precise readings of the muscle and brain activity, a more efficient exercise to assist patients with neuromotor impairments is possible. The ability to allow the patient to program their exercises on an ambidextrous system is what makes this project stand out from the rest.

The fourth generation of the robotic exoskeleton for neuromuscular rehabilitation and exercise will improve the lives of patients suffering from the decreased motor ability. The design is optimized to ensure a sustainable and cost-efficient apparatus that puts the needs of the consumer at the forefront.

ACKNOWLEDGMENTS

The design team thanks Dr. Donald Peterson, Dean of the College of Engineering at Northern Illinois University, for his mentorship and continued support throughout the design process, as well as the professors of the Mechanical Engineering, Biomedical Engineering, and Art and Design departments of Northern Illinois University, for instilling the knowledge necessary for this design. The design team would also like to thank the students involved in the three previous generations of the exoskeleton.

REFERENCES


Autonomous Vehicle Sensor Data Processing to Enable Control of Material Handling Equipment

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Abstract— The project detailed below is a multi-sensor system that will attach on to manual warehouse vehicles. The sensor system will collect and process data from the surrounding environment. The data will then be used by the vehicle to navigate the environment. The essential features of the project are how the sensor system will interpret the environment data; how it will parse and pull valuable information out of specific data streams. The motivation behind this project is to see the limits of this new emerging automation technology and the future application of this technology in the material handling field.

I. INTRODUCTION

Currently on the market there are a variety of robotic kits that turn manual robots into Autonomous Guided Vehicles. These Autonomous Guided Vehicles or as industry calls them AGVs are the future of warehouse loading/docking and transportation within warehouses and construction environments. UniCarriers’ Americas came to the team to get assistance in making their own version of an autonomous robot kit.

The reasoning behind this comes from the lucrative market that AGVs have in the warehouse environment. Since the market is heading towards this direction, and in order to have a step up on other AGV manufacturers, UniCarriers wants to understand the sensor technologies and integration details required for a fully Autonomous Guided Vehicle. After understanding the process of turning a regular robot into an AGV, UniCarriers can more effectively support their Autonomy partners during integration into existing products, while developing platforms customized for AGV/AMR applications.

To accomplish this goal UniCarriers approached our team with various sensors and computer hardware they felt would be vital to the positive outcome of this project. The sensors included were the TopoSens 3 Ultrasonic Sensor and Intel RealSense Visual Sensor. These sensors will send data to their corresponding Raspberry Pis. The data will then be aggregated onto one PI where it will be mapped inside of the program Robot Operating System (ROS). The data points will then be superimposed on top of each other to create a detailed map of the surrounding environment. From there the proposed program would then split up this environment map into specific quadrants, where from there it would use occupancy grid mapping to measure distances between data points in relation to the robot itself. The bulk of the project will be this program and how we get these two sensors to relay data back and forth to each other.

II. MATERIALS AND METHODS

A. Robot Operating System (ROS)

ROS is not a physical device in the system, but a flexible framework designed specifically for robots and other micro-controllers. ROS was designed to be as thin as possible so that other programming languages could easily implement ROS. ROS is integrated into the system because it acts as the framework that processes all the sensor data collected within the system. That processed sensor data can then be visualized using different existing ROS modules; one of which is called RViz. RViz is a graphical interface that allows the information to be visualized, by using plugins for available topics [4]. Below is an example of ROS plotting ultrasound data from the TopoSens 3 sensor.

Figure 1: Sensor Data visualized on RViz

B. TopoSens 3 Sensor (TS3)

The TopoSens 3 is a sound-based sensor; meaning it uses ultrasound waves to map the surrounding environment. The form of the sensor is a rectangular shaped object, the dimensions are roughly 9 x 3 x 1 cm. It has a field of view of 140° x 140° and can scan up to five meters with a precision of ± two mm. The TS3 functions by sending ultrasound waves at intermediate points in time, the sound waves rebound and are then picked up by a high-frequency microphone inside the sensor. All this data concerning the ultrasound waves are generated; the time traveled, the distance crossed, and the angle of the wave are all measured and sent into ROS.

Figure 2: TopoSens 3 Ultrasonic Sensor
C. Intel RealSense Camera

A product that has a range of depth and tracking technologies designed to give machines and devices depth perceptions capabilities and much more[5]. The Intel RealSense Depth Camera uses an RGB sensor and infrared projector to create a view of the environment surrounding it. The unit also contains an inertial measuring unit (IMU) that can detect rotations and movement in six degrees of freedom. This IMU uses a gyroscope to detect rotation and movement in three axes. The Active IR Stereo projector has a field of view of 87° x 58° x 95°. The function of the RealSense camera is to provide a secondary data type that ROS can parse through. The parsed sensor data then can parse through. The parsed sensor data then can be integrated with the sensor data from TopoSens 3 and then combined sensor data can be visualized inside of Rviz.

III. RESULTS AND DISCUSSION

The final iteration of this project includes a custom-made sensor module to house the multiple sensors. The sensor module was then mounted on top of a prebuilt robotic testing unit. This testing unit was used to collect data and simulate a standard manual vehicle that would be found in most common warehouses. The findings for each sensor are as detailed below.

TopoSens 3 Sensor

Initial results from the TS3 were promising; however, the data points gathered revealed several flaws. External high frequencies caused false data points to appear within the ultrasound map created by the TS3. As such, this specific sensor would be hard to implement within a warehouse context because most machinery emit high frequency waves; these ultrasound waves will cause false positives to appear in the environment which will lead to the AGV trying to navigate past objects that may not actually exist in the given environment.

Intel RealSense Camera

Documentation for this sensor describes the maximum depth range to be up to ten meters with a slight variation depending on lighting. However internal testing revealed that a realistic range for this sensor was around five meters; with any practical data being only generated when the sensor was within two to three meters away.

IV. CONCLUSIONS

The initial project scope detailed a system that supported a fusion of different sensor types. The fused sensor data theoretically would give a more accurate representation of the surrounding environment. The practical data gathered from these specific sensors however has led to be less insightful than initially thought. The current completed system follows a modular approach, which in the future will allow for easier implementation of new sensors. A combination of new sensors in conjunction with the existing sensors may lead to a successful project goal of a fully operational AGV kit.

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REFERENCES

ANCCAR: Active Noise Cancelling System for a Automobiles

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Abstract—Modern vehicles aim to provide supreme comfort to daily drivers using a variety of methods such as panel insulation, improved tire treads, and suspension design. However, these systems wear down over time and often fall short of optimal noise reduction within the cabin. This project aims to alleviate the noise pollution within the cabin of a vehicle using a non-invasive system to actively measure noise within the vehicle and produce an inverted output to create a true noise cancellation. The system targets the driver and passenger inside the vehicle by uses two microphones and two speakers, an audio box, microcomputer and amplifier to process the undesired noise. The non-invasive installation is created by using 3D printed housing components for all the electronics, such that panel retainers readily available within the vehicle can be substituted for the provided screws. This prevents the need for any drilling or threading of any surfaces of the vehicle. Power is supplied through the vehicle battery and into a fuse box and power converter to control the operating and steady state voltage and amperages.

I. INTRODUCTION

Over 200 million Americans drive their vehicle to and from work on a daily basis, often times at highway speeds [1]. The droning noise from the vehicles engine and tires contacting the road surface can be both annoying and lulling to many drivers. The majority of daily commuters are in a vehicle over five years of age. This indicates that the vehicles are worn in many ways which often leads to greater noise pollution passing through the cabin of the vehicle. Modern vehicles attempt to combat this noise pollution by adding insulation to the inner frame of the vehicle, however this tends to be very costly and adds a large amount of weight to the vehicle. As a result, drivers sacrifice fuel economy for peace and quiet. Since the automotive industry is not fully vested in electric vehicles, some form of noise cancellation must be available, especially for older vehicles since they dominate the majority of roadways.

Previous active noise cancelling systems utilize a collection of inertial sensors as well as multiple microphones to capture vehicle motion data, process it through an algorithm, and output the cancellation throughout the vehicle cabin. The primary downside of such kind of system is the excessive cost, difficulty of installation, and limitation of compatible vehicles. The ANCCAR system tackles all these challenges in one effective solution and is affordable and feasible for nearly all vehicles.

II. MECHANICAL DESIGN

The ANCCAR system uses a set of 3D printed housings to secure each electrical component to the vehicle in a safe, non-invasive, and spacing limiting method. The system consists of two speaker housings printed in SLA, a control board printed in FDM, as well as a housing for an amplifier, a microcomputer, and an audio box which is printed in SLA.

The speaker assemblies come preassembled and are suspended from the roof of the vehicle’s cabin via four
neodymium magnets. The placement of the speakers should be placed behind the driver and passenger’s head to prevent blocking driving visibility. The neodymium magnets generate a net vertical pull force of over 80 pounds. This ensures that the speaker assembly (weighting approximately 1.5 pounds) will not detach from the cabin roof from any large shock load or vibration which the vehicle will undergo. Each electrical housing as well as the control board are easily assembled using the provided machine screws. These screws are set into helical inserts which prevent them from backing out due to vibration. Additionally, the use of helical inserts eliminates the need for users to have additional tools beyond the provided 2.5mm hex key. Furthermore, a double flip safety switch is attached to the inside panel of the driver side center console via a Velcro strip. This eliminates the need for fastening the switch to the body panel yet creating an easy use on/off switch for the driver to control the operation of the system. In most vehicles the control board will be placed underneath the passenger side glove box. This is both beneficial for not interfering passenger space and creating a discrete wiring path. The provided microphones come with a clasp mechanism that allows them to be securely placed on the inside bar of the head rest.

Figure 3: Microphone placement

Once more these microphones are positioned such that they fall within one inch of the head rest so that they do not interfere with the driver’s vision. In the event the vehicle does not have a detachable head rest, an alternative mounting solution can be made readily available.

III. ELECTRICAL DESIGN

A. Computing System

The main processing power for the ANCCAR comes from the LattePanda but is not actually the microcomputer inside, it is the Arduino Leonardo that is imbedded on the back side of the board. This board uses an ATmega32u4 chip with 32KB of memory and 2.5KB of ram. This allows a code be uploaded from the microcomputer to the Arduino for daily operation and signal p-processing.

B. Operating

Normal operation uses two compact microphones with an audio interface to create an analog signal. This signal is processed through the Arduino Leonardo which outputs a corrected analog signal. This signal is sent to a compact 2 channel amplifier that powers two low-profile speakers behind both of the front seats. The noise inside the cabin of a vehicle is collected and corrected through actively sampling and filtering in real-time fashion. This system uses many types of filters in order to achieve approximately half of the engine noise while leaving many high frequency sounds unattenuated. The output is limited in its magnitude to make sure the system is stable.

C. Power System

The system is powered with the stock electrical system of the vehicle. A fuse block and power converter are located in the engine bay to provide safe fused 12 volt and 5-volt sources to power all of the components. A 12 volt connect is wired to the amplifier and a 5-volt connection is powered the LattePanda. The LattePanda power rail is connected to the USB ports, the Arduino Leonardo board, and the microcomputer screen port. This allows all components power instantly whether the microcomputer is on or off.

IV. ABBREVIATIONS AND ACRONYMS

FDM: Fused Deposition Modeling
SLA: Stereolithography
ANC: Active Noise Control

V. CONCLUSION

The ANCCAR system allows common road and engine noise to be collected, analyzed, and inverted to cancel most of the noise pollution within the vehicle’s cabin. The system is intended for a user friendly, noninvasive installation method. This system will provide optimal noise cancellation without hindering the weight and fuel economy of the vehicle. Moreover, the system does not break the bank into parts and it is a cost effective manufacturing method. The reduction of noise pollution in the vehicle will make for a much more comfortable ride for the driver as well as allowing them to have more focus and less irritability on longer drives.

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REFERENCES

Low Cost Thermophotovoltaic System
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Abstract—This paper describes the process of creating a low cost and efficient thermophotovoltaic system. The system is capable of producing up to 5V of electricity using an infrared heat source. The system is also built to be compact so the user can transport it with ease.

Keywords—Photovoltaic, Emitter

I. INTRODUCTION

Energy production is one of the most important parts of modern life. Without the availability of electricity, today’s society would not be able to exist. Throughout time there have been numerous ways of generating power. From giant factories, to wind turbines, and even hydroelectric dams, humans have invented processes to harness vast amounts of energy, however, each system has its set of drawbacks.

For starters, most power generators take up a large amount of space. It may vary from a generator the size of a room, to a powerplant that takes up acres of land. These traditional means of power generation tend to be inefficient, and most times harmful to the surrounding environment.

One promising solution to these concerns is the method of thermophotovoltaics, due to their low cost, high efficiency, and ease of use. Thermophotovoltaic systems operate similarly to a solar panel, however, instead of relying on sunlight to generate electricity, thermophotovoltaics only require a source of heat.

In this paper, we will be demonstrating how our photovoltaic system create clean and efficient energy, and explaining why this new method should be considered, due to its cost, reliability, and ease of operation.

II. MATERIALS

The photovoltaic material chosen for this device was Indium Gallium Arsenide Antimonide (InGaAs). This material was chosen due to its ability to capture infrared radiation and low optimal wavelength dependence [1]. The photodiode chosen was the Model: LSIPD-L2, shown in Figure 1. This model was chosen due to its operating temperature and high forward voltage.

For the emitter, carbon graphite was used as a material capable of radiating at near black body infrared heat at low temperatures. The heat shield and mounting location of the photodiode cells used 304 stainless steel (SS) for its ability to withstand 2000°F for extended periods of time without deformation and fatigue failure. Further insulation was added to the exterior for added safety using Fyre Wrap that that corresponds to ASTM E2336 standards.

III. POWER PRODUCTION

A. Combustion Chamber

The combustion chamber was a purchase component of the thermophotovoltaic (TPV) system. The selection was done by fuel source as well as temperature output; for these reasons the Bernzomatic TS8000, which can be seen in Figure 2, was chosen for its versatility and control mechanisms.

The TS8000 has an average temperature output of approximately 1750°F using propane as the fuel source, with an option of MAPP gas if preferred by the user. The temperature of the combustor can be controlled with a variable valve on the combustor itself. The other capability that the combustor has to offer is the ability to lock it in the on position for hand free operation. The tip of the combustor incorporates a turbulent promoter for maximum efficiency, this tip is press fit into the emitter portion of the TPV system.

B. Emitter

The Emitter portion of the TPV is made of a carbon graphite rod. The emitter is the core of the TPV system. The emitter radiates near black body infrared heat which is used by the photovoltaic cell to generate the electricity [2]. The emitter needs to achieve the near black body infrared radiation at a low temperature without risking deformation. The carbon graphite was selected based on its success rates with carbon being used in small infrared space heaters for personal use.

Figure 1: Photodiode

Figure 2: Bernzomatic TS8000
The carbon graphite emitter did have challenges involved in the machining process due to the dangerous nature of machining any brittle carbon-based materials proper ventilation and machines are required, and in this case, electrical discharge machining (EDM) was selected as the safest practice for manufacturing the emitter portion. The stock carbon graphite is a rod 1.75" in diameter with two concentric inside diameters (IDs) the smaller portion that the combustor tip is press fit into is 1" long and 0.629" in diameter. The heat chamber is 1.5" in diameter and 4" long creating a thin wall of 0.25" for the emitter to achieve operating temperature in a timely manner.

![Figure 3: Carbon Graphite Emitter](image)

The 4" heat chamber allows for maximum surface area to be heated to the temperature required for the infrared radiation contributing to the power capable of being produced by the photovoltaic cell.

C. Photovoltaic Cell

The photovoltaic cell is where the electricity will be generated in the system. The electrical circuit is comprised of three photodiodes, all oriented to capture the most amount of infrared radiation produced by the emitter. Once the photons are captured, the photodiodes covert those photons into electricity which is sent out of the device and into the receiving system. The photodiodes have a maximum operating temperature of 80°C, so it is crucial that they stay within that range.

IV. RESULTS

Unfortunately, due to the COVID-19 pandemic, testing was put on hold and the result was a virtual device that was used for multiple simulations to determine the results. The test simulation according to ANSYS the outer surface of the emitter will average between 1600 and 1700°F at the outer surface to radiate the infrared heat required for the photodiode cells to reach maximum functionality. The photodiodes that were ordered for this system were never received due to the virus, therefore a similar type of photodiode was used in order to obtain a benchmark. The replacement was a QED 123 IR LED, which behaved similarly to the desired photodiode, but generated less power. A lab test resulted in a voltage of 2.6V which can be seen in Table 1. The test resulted in only half of the expected voltage of the InGaAs photodiode. With the desired photodiode, an estimated 5V would have been able to be achieved due to its higher forward voltage.

<table>
<thead>
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<th>Light Source Distance (In)</th>
<th>Voltage (V)</th>
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<tbody>
<tr>
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</tr>
<tr>
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<td>2.3</td>
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ACKNOWLEDGMENT

The authors would like to thank Dr. Tariq Shamim, Chair of Mechanical Engineering at Northern Illinois University, Matthew Kleszynski for their continued technical support throughout the research. The authors would also like to thank Mike Reynolds for his recommendations for manufacturing technical components, and Edward Miguel for opening the lab for testing the photodiodes and his technical recommendations for the electric circuit.

REFERENCES


A Multisensory Gamma Entrainment Apparatus for Rodents

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Abstract — New treatments are needed for detrimental neurological diseases such as Alzheimer’s disease and stroke. Certain auditory and visual stimulation has been shown to reduce neuropathology in rodents. The apparatus discussed in this paper allows researchers to expose rodents to multisensory stimulation at various frequencies while allowing the rodents to remain in their home cage. An attempt to create a noninvasive and wireless EEG for rodents is also described. The design consists of gold cup electrodes, a premade printed circuit board, coaxial cables, a GUI, and a flexible suit that fits on a rat. More testing is needed to complete a functional noninvasive EEG.

I. INTRODUCTION

Neurological disorders such as stroke and Alzheimer’s disease cause suffering across the world. Recent research suggests that specific patterns of synchronized multisensory (auditory and visual) stimulation can improve cognition and reduce pathology in mouse models of Alzheimer’s disease [1]. Equipment that exposes rodents to user set patterns of synchronized auditory and visual stimulation is necessary for further studying the effects it has on the central nervous system. The equipment should also include an electroencephalogram (EEG) to monitor rodent brain activity as stimulation occurs. In this paper, a design for an apparatus that exposes rodents to multisensory stimulation and measures their brain activity is discussed.

II. BACKGROUND

The design allows for the multisensory stimulation to be user set to pulse at frequencies that are a multiple of 10 Hz and are between 20 and 80 Hz (inclusive). It can also be set to a random frequency mode, in which a frequency is randomly determined by a uniform distribution from 20 to 80 Hz at the beginning of each pulse. Therapeutic benefits of specific frequencies can be explored, and the random frequency mode can be used for control groups. The 40 Hz frequency stimulation is expected to be used because it is the frequency at which gamma entrainment therapy occurs.

The immediate effects of multisensory stimulation can be observed with an EEG. The main purpose of the EEG is to verify that the brain waves resulting from gamma entrainment are occurring. The EEG is designed to be noninvasive, which removes the need for time intensive and dangerous surgeries required for invasive EEGs. A circuit board from OpenBCI called the Ganglion, an OpenBCI graphical user interface (GUI), and gold cup electrodes are used for recordings. A rat suit was made to hold the circuit board and secure the electrodes in place. The design also requires the use of electrode gel. The EEG is designed to be easy to use, safe, reusable, and fit rats of different sizes.

III. DESIGN

The minimum requirement for use of the apparatus in an experiment is that the stimuli run as expected. Input to the stimuli is controlled with a dial that is a potentiometer. As the dial is turned, the frequency of the stimuli is changed by an Arduino Uno. The frequency that is set by the user is clearly displayed on an LCD screen near the dial.

The desired properties of the EEG include accuracy, preciseness, and production of data that can be saved. Input to the EEG comes from two gold cup electrodes. One electrode is placed on a shaven rat head and superior to the sensorimotor cortex of the rat. The reference electrode is placed on the side of the head, or elsewhere on the rat. The signal from the electrodes is wirelessly transmitted to a computer via Bluetooth. The EEG voltage versus time graph and fast Fourier transform (FFT) per second can be viewed in the OpenBCI GUI. The signal can then be saved in the GUI for later analysis.

IV. MATERIALS AND METHODS

A. Multisensory Stimulation

The potentiometer controls a voltage that is an input into the Arduino Uno. The Arduino Uno microcontroller was coded to detect eight equally sized intervals of voltage. Seven for the frequencies between 20 and 80 Hz, and one for the random frequency mode. The frequency value is displayed on the LCD, and a loop runs that pulses a square wave current through the LED strip with a duty cycle of about 50%. The light is white, and the auditory stimulation is a 10 kHz sound that turns on at the same time as the LEDs and remains on for 1 ms. The design for the duty cycles was taken from [1]. At the end of each pulse, the voltage input from the potentiometer is checked. The box has no floor, so it can be placed to enclose a rat’s home cage that remains within the box during stimulation sessions. The piezoelectric speaker is placed on the ceiling of the box and faces down. The LEDs are wrapped around the box. The box is transparent so rodent behavior can be observed during stimulation. The stimulation box is shown in Figure 1. If components break, function can be maintained without technical engineering knowledge by replacing individual parts.
B. Rat EEG

For EEG testing on a human subject, one electrode was placed at the right visual cortex, and the reference electrode was placed at the left earlobe. The OpenBCI GUI was used to analyze signals. To analyze noise, two electrodes were placed on one human arm to induce a small differential voltage. The suit used to place the electrodes on the rat was made from spandex and Velcro to allow for physical flexibility and use on multiple rats. An unfinished prototype suit was tested on a rat.

V. Results

A. Multisensory Stimulation

The frequencies and duty cycles of the stimuli were verified with an oscilloscope and results indicated expected values. With one piezoelectric speaker within the box at the 40 Hz frequency, the amplitude of sound measured within the box was 70 dB. When the piezoelectric speaker was not inside the box, the amplitude of the sound from about the same distance from the speaker outside the box was measured to be about 57 dB. The increase in sound wave amplitude inside the box is possibly due to echoes happening within the box. Outside the box, the measured decibel levels were as low as 50 dB when the piezoelectric speaker was set to pulse at 20 Hz, and as high as 60 dB when the frequency was set to 70 Hz. The intensity of the lights can be controlled with a resister in series with the LED strip. One flaw with the design is that when the dial appears still, the resistances within the potentiometer circuit changes slightly, which can cause the user set frequency value to fluctuate between two frequencies if the dial is not set unequivocally within the boundaries of the interval, which happened only once during testing.

B. Rat EEG

Measurements displayed on the GUI for the human EEG resembled those of a typical EEG signal. However, human gamma entrainment, which should be a 40 Hz EEG wave, was not observed with the stimuli, although gamma entrainment has been shown to occur in humans [2].

Before coaxial cables were used, noise due to displacement current from the stimulation circuit was visible in the FFT. Figure 2 shows noise from the stimulation circuit while the 40 Hz frequency was running. After the coaxial cables were grounded and used, noise was reduced (Figure 3).

VII. Discussion

The stimulation box works as expected. The stimulation can be run at the correct frequency and is ready for experimentation. The increase in sound amplitude due to the echo may interfere with the intended audio stimulation, which is a problem that may be fixed by padding the walls of the box with acoustic foam. The noninvasive rat EEG is unfinished, but significant progress has been made. The suit must be connected to the coaxial cable gold cup electrodes and tested with a rat.

Acknowledgments

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References


Automatic Piston Pin Internal Diameter Defect Detection

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Abstract—Inner diameter inspections of piston pins are manually performed via a GO/NOGO plug gage inspection. Automation of this physical process may be achieved through the implementation of an appropriately controlled and situated linear actuator. To accommodate for varying piston pin sizes, the physical architecture of the design is constructed such that the design may be changed manually prior to a production run. To minimize complexity during adjustments, all physical adjustments are based around placing the center of the piston pin into a recurring target position. Since this target position does not change, the prototype maintains the capability to adjust itself across three different axes to account for the length of the pin, the vertical center of the pin, and the horizontal center of the pin.

I. INTRODUCTION

Burgess-Norton Mfg. Co. is a manufacturer of powder metal parts and is the world’s leading manufacturer of piston pins. Millions of piston pins are supplied every year to major automotive industry partners. These pins must meet rigorous international standards and customer specifications in order to be safe for automobile use.

In fiscal year 2019, Burgess-Norton spent in excess of $100,000 on internal sorting labor costs. Current sorting activities are manual, highly operator dependent, and have extremely inefficient cycle times. As a result, many internal key performance metrics are negatively impacted, including customer on-time-delivery, expedited freight charges, and unplanned overtime.

To alleviate these costs, a prototype was developed to automate a high-impact sorting activity, inner diameter (ID) plug gage inspections.

Critical criteria of inner diameter inspections revolve primarily around ensuring that there are not pins from separate production orders being mixed in. Given the variety of pin sizes produced by the client and similarity between externally measurable criteria (such as length and outer diameter), an inspection of the inner diameter is necessary to ensure that mixing has not occurred. Inspectors employ a simple GO/NOGO gage called a plug gage that is inserted into the ID. Several customers of the client require that mixed pins are inspected for in every shipment, resulting in an ongoing demand for automation of this process. Due to the inherent nature of the process, pins will sometimes become mixed on accident. In these unpredictable instances, a plug gage sorting may be necessary. Automation of a plug gage insertion and subsequent reading of the GO/NOGO gage depth will eliminate currently required manual labor. This same method of inspection is also employed for other related issues such as detecting out-of-tolerance ID dimensions or inspecting for a collapsed ID (a potential defect in the piston pin manufacturing process). Ultimately, plug gage insertion automation and processing will cover a wide range of inspections.

II. METHODS AND MATERIALS

All structural components are fabricated from 1/4-inch 1018 steel to ensure structural integrity and ease of manipulation for potential future adjustments deemed necessary. For initial prototyping purposes, an Arduino was utilized to demonstrate a basic level of automation over one of the features of the prototype, an automatic gate/rejection/acceptance subassembly. This physical feature is rotated by an Oriental Motors PK299-03BA Stepper-Motor that is controlled by a CSD2145T Driver and an Arduino Uno R3. For scaling beyond a prototype, a PLC will be required for industrial-level control systems engineering. The linear actuator is a pneumatic system that will be using a solenoid bank and air pressure supply in accordance with the industry client’s in-house systems. The actuator is similarly controlled by a PLC.

Fig. 1 An overview of the entire system. The piston pin that is inspected is the red cylinder.

All methods of securements for adjustable aspects of the design involve screw fasteners and nuts and for locking in place. The method of holding varying sized plug gages was
solved by modifying a pre-existing design that enables a wide range of plug gages to be used via a simple setup procedure. An additional minor modification also made fastening of this component to the front face of the actuator functionally effective. For the physical architecture of the project, a three-axis piston pin positioning is utilized.

III. RESULTS

The prototype design is capable of maintaining the necessary points of contact to ensure smooth piston pin motion while also allowing the necessary three-axis level of maneuverability. With a plug gage inspection, numerous different types of inspections may be performed depending on the situation. The system is appropriately setup to allow mixed pin inspections (where adjustment of the actuator is unnecessary) as well as collapsed ID inspections (where adjustment is necessary). The design will function for piston pins within an ID, OD, and length varying 0.2-0.6 inches, 0.5-1.25 inches, and 0.5-4 inches respectively. One considered obstacle was that minor variance in the tolerances of the piston pins would result in making a recurring target position too difficult to achieve. Initial experimentation revealed that the amount of deflection permissible in the pin is a matter of the distance of the chamfer on the end face of either the plug gage or the pin. The variance permitted in the relevant end face components of the piston pin are, at worst case scenario, two orders of magnitude lower than the minimum machinable chamfer length on the plug gage.

Fig. 2 The three-axis positioning system from the perspective of the side of the pneumatic actuator. The purple Adjustment Holder component is responsible for adapting to different piston pin widths, while the separate ramp components are adjustable for the pin’s vertical positioning.

IV. DISCUSSION

A successful, production-ready implementation will depend on several extrinsic and intrinsic factors of the project. The tested cycle time of a single inspection will be a major influence on the future of the external aspects of the design such as the chosen location to implement the design within the client’s facility. Subsequently, the method of material introduction and removal will also vary based on the chosen location. If chosen to be in a pre-existing production line - implying a sufficiently fast cycle time - the cost of implementation outside of a PLC’s relevant components is insignificant. If the reverse is true, then most methods of material introduction or removal will present significant costs. Periodic manual introduction could present a desirable medium between these cost scenarios.

Several steps have been taken to mitigate potential issues that may occur during testing or production runs. In considering the potential variance in the center of a piston pin’s ID, a chamfered plug gage is utilized to ease in the deflection of the piston pin. Additionally, instructions are provided to intentionally offset the target position of the system so that the piston pin does not deflect downward or forward into a solid surface. To prevent the possibility of jamming, a double-acting linear actuator was selected with the operating psi suggested at relatively low pressures.

V. CONCLUSION

Future incarnations of this prototype should seek a means to increase the cycle time of a single inspection without sacrificing the pressure applied during a manual plug gage inspection. In addition to this development, an inexpensive and innovative means of introducing piston pins into the system should be researched or developed to further the feasibility of the design in a production-ready environment. Implementation of a PLC to fully coordinate the system is also a must.

Of perhaps the most significance during this prototyping phase is the development of an inexpensive and piston pin based three-axis positioning system. The end goal of the project to conduct an automated plug gage inspection necessitated such a system, and consequently this design may be repurposed outside the region of plug gage inspections that could not previously be automated due to the lack of such a system. Research into further automation stemming from the core of this design could save the industry client significant time in inspections that today are performed manually.

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Special thanks go to the industry client for whom this project was undertaken. Thank you, Elisa Sorrentino and Kent Wrenn, for organizing the existence of this project and providing the necessary resources for Team 35’s success.
Abstract — Wahl Clipper Corporation is the industry leader in both professional and consumer grooming products. In an effort to explore new technologies, Wahl would like to investigate an educational tool for their professional customers. The proposed Intelligent Clipper and Manikin System is designed to provide a user with the feedback needed to both influence and correct the user. In doing so, the user should be able to perform the haircut with minimal outside instruction. Research has shown that there are very few tools currently available to professionals that provide this function. This system utilizes Wahl’s most popular professional clipper, the Cordless Magic Clip, and a reusable manikin head. The feedback system incorporates RFID technology, Hall Effect sensor arrays, and individually addressable LEDs in conjunction with a modified taper lever mechanism accessible through Bluetooth technology. This feedback will effectively assist the user in performing the haircut. The system was be primarily used in a professional educational setting but has potential to be useful to consumers as well. 

I. INTRODUCTION

For over 100 years, Wahl Clipper Corporation has been a pioneer for the grooming industry with their start coming from the very first electromagnetic hair clipper that was patented in 1919. In order to maintain their status as a trailblazer of the grooming industry, Wahl is always looking for new technologies that will broaden their scope and benefit their customers. This has led them to an area that is sometimes overlooked – professional barber education. At the time of this project, there are currently very few tools that specifically target this need. In order to address this gap, Wahl is working to develop a system that will assist a user in performing a haircut with little outside instruction. The Senior Design team has been tasked with creating a prototype of a system that will provide the user with enough feedback to be able to perform the haircut correctly. The proposed design uses a combination of electrical and mechanical components in order to analyze the user’s technique and provide feedback.

II. THE DESIRED HAIRCUT

One of the most popular haircuts of the modern day is the Fade haircut. This haircut can be interpreted to include many styles, so the design team decided to limit the haircut to the Bald Fade haircut. It has been determined that this haircut includes three main sections of different lengths that can be achieved through the use of three different length combs provided to the team by Wahl. These combs include a gray comb which cuts hair to 1/16th of an inch in length, a red comb that cuts hair to 1/8th of an inch in length, and a purple comb that cuts hair to 1/4th of an inch in length. Each of these comb lengths correspond to one of the three sections of hair that was previously mentioned.

In order to perform the haircut, the user would begin with the shortest length comb, in this case the gray comb, and work up to the next zone. Once the next zone has been reached, the user switches out the comb to the next shortest length comb or the red comb in this case and works up to the final zone. The final zone requires the longest length comb which is the purple comb for this haircut. In order to successfully complete the haircut, the user will need to blend the lines between the various sections by using the taper lever mechanism that will be outlined in further detail later on. The user will be provided with feedback to outline the location of the zones as well as the clipper’s position in relation to the manikin head. This will assist the user in knowing whether they are correctly performing the haircut.

III. MATERIALS AND METHODS

The proposed system is composed of two main physical components including the Wahl Cordless Magic Clip clipper and a reusable manikin head. Several electronic components are housed within the clipper including an Arduino Nano 33 IoT and a modified taper lever mechanism. The clipper also has a neodymium permanent magnet mounted on the back of the clipper blades and unique RFID tags adhered to the clipper combs. The manikin head houses the remainder of the components including an RFID reader, Hall Effect proximity sensing arrays, Arduino Uno, Arduino Nano 33 IoT, and individually addressable LED strips. The electronics housed in the clipper are powered with the existing battery in the clipper and the components housed in the manikin head are powered with an external rechargeable power bank. The communication between the clipper and the manikin head is facilitated by the two Arduino Nanos that are housed in both of these parts. The Bluetooth communication is used to send information about the taper lever position from the clipper to the manikin head. This information will be used in conjunction with the information from the RFID reader and Hall Effect proximity sensing array to provide the user with feedback using the LEDs in the manikin head.

The modifications made to the taper lever mechanism allow the system to know which position the lever is in based on where the taper lever is making contact with the clipper case. As seen in Figures 1-3, there is now a pogo attached to the taper lever that allows the lever to act as a switch when making contact with the clipper case. The various contact locations correspond to the blade set being fully open, fully closed, and halfway between the two. As seen in these figures, there are various leads coming off the contacts. These leads would be physically attached to an Arduino Nano 33 IoT that would act as the peripheral module in the Bluetooth communication scheme. This peripheral Nano would send data about the taper lever position back to the central Nano that is located inside the manikin head. This data would be
used in addition to the RFID tag data to light up specific LEDs inside the manikin head that correlate to which section of hair should be cut. The different positions of the taper lever allow for proper blending between the zones of the haircut which is very important to the overall success of the haircut.

RFID technology is another component of the design that allows the system to provide the user with useful feedback. As mentioned previously, the color coded combs that are being used for the different lengths of hair have unique RFID tags attached to them as seen in Figure 4.

This allows the RFID reader that is housed in the manikin head to know exactly which comb is on the clipper at any time. The team has designed the manikin head in such a way that the different sections of hair will light up as they need to be cut. The light fields, as they are being called, act as a guide for the user to know where to cut based on the comb they have attached and the taper position that they have the lever in.

The RFID technology also works in conjunction with the Hall Effect proximity sensors so they know which section the user should be staying within. There will also be an LED collar that will be placed around the neck of the manikin. This will allow the team to provide visual feedback to the user based on the combs and position sensing. The LED collar will light up the color of the comb that is on the clipper. This LED collar will then flash based on whether the user is starting to get close to the boundary of the zone or if they have left the zone completely. In doing this, the feedback is intended to correct the wrong behavior and provide guidance on where the user should be cutting.

One of the most important parts of this design is the corrective feedback that it provides to the user. This is done through the use of Hall Effect proximity sensing arrays.

IV. CONCLUSION

The system that was designed should be able to walk an untrained user through the process of performing a Bald Fade haircut. Due to extenuating circumstances, the physical integration of the individual parts could not be completed. The result was a system where each part was shown to work individually, which implies that the design would theoretically be able to function when fully integrated.
A Short-Range Radar to Detect Chest Movement of a Still Person

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Abstract—This project presents an FMCW radar system using off-the-shelf components controlled by a micro-computer. This device can be used as an experimental platform to test various ideas in vital signs detection research. The design expands on the MIT radar project to use as a non-contact solution to detect chest movements of a still person. As a backup system for comparison against the MIT device, an alternative independent radar system, Xethru, was used to study additional ways to detect vital signs.

I. INTRODUCTION

This project is a short-range radar to detect chest movements of a still person in which a microcontroller is used to analyze the real-time data. The current design is a compact computer based low-cost low-power short-range frequency modulated continuous wave (FMCW) sensing system. The design architecture enables the detection of subtle displacement such as breathing and heart rate of a human being and displays the biometric information in real-time.

The device is based on high directivity PCB Yagi antenna, continuous ramp signal generation and synchronous modulation for linear sweeps, rapid transition analog filtration, and real-time digital signal processing. The raw analog data is acquired from a radar sub-system and delivered to a single board computer (SBC) for low latency audio-based analysis. The DSP implementation utilizes known discrete Fast Fourier Transformation (FFT) algorithms to facilitate plotting data on a per frame basis in real-time. The result is an efficient and compact portable device able to acquire and plot accurate biometric data in real-time.

The XeThru used in this project is a single chip radar subsystem that measures breathing patterns of a still person and connects to a computer for real time data analysis. It was used to show us an example of a similar product on the market.

II. HARDWARE

The radar sends sweeps with linearly increasing frequency at 1 kHz repetition determined by the chirp rate of the modulator to a data acquisition platform. For every sweep the heterodyne signal is received by a 10kHz low pass filter, sampled in 32-millisecond frames and Fourier transformed (512-point DFT) so that returns from the target at different distances can be separated. Then the phase of one of the DFT frequency bins (N/2-1) associated with the past distance to where the target is located is chosen. The same processing is done for all sweeps and plotted in real time.

A. RF Front-end

The radar system begins with the modulator to drive the FMCW signal to produce a linear ramp to modulate the input to the oscillator. The oscillator is a Voltage Controlled Oscillator (VCO) where the input is proportional to the transmit frequency. Utilizing this VCO supports the FMCW system where the transmitting antenna will continuously propagate waves with varying frequencies and the receiving antenna will continuously receive waves. The output from the oscillator will then lead into the attenuator, which is used to lower the gain for the signal.

The power splitter works by using a single input to power two outputs. It is important to use a splitter with a high return loss and low insertion loss since the system is required to power two outputs. Low-noise amplification is applied to the microwave in two stages: once before transmission to compensate for line attenuation, and once after the reflected wave is received to compensate for attenuation caused by the transmission medium.

Directional patch antennas operating in the 2.4 GHz ISM bandwidth are used in this design for both the transmitting and receiving antennas. Upon receiving the reflected microwave, the signal is mixed with the transmit signal that was split before transmission. The mixer produces a center tapped intermediate frequency (IF) product signal from the ring modulator with a local oscillator (LO) frequency of approximately 2.6 GHz and marginally lower RF frequency, due to the Doppler effect, creates a conversion loss of approximately 5.44 dB.

III. SOFTWARE

A. Signal Processing

The signal processing stage was approached using object-oriented programming to take advantage of vectorizable algorithms. Written in C# [2], a real-time DSP strategy was...
implemented that utilizes the forward Fast Fourier Transform (FFT) algorithm: 

\[ x_j = \sum_{k=0}^{n-1} z_k e^{\frac{2\pi i j k}{n}}. \]

B. Chest Movement Testing and Results

When testing the software, audio signals are used to mimic the chest movement breathing signals that will be used in the final demonstration. Using a microphone, the software captures audio data in real time, performs the FFT, and plots it on an interactive graph (Figure 2). The heart normally beats 60 to 70 times per minute, while the breathing rate is about one-fifth of that. Using this information and the incoming signal, the heart rate can then be calculated by \( \frac{60}{\text{Duration of R-waves}} \) and then plotted. Shown in (Figure 3), the results show an average heartbeat of about 82 BPM which was done via non-contact means. This was tested using the LattePanda MCU/Display which allows the user to obtain data while portable. A final graph was then made to track chest movements which has output data similar to that of the Xethru, which was the goal of this project (Figure 3).

X4M200 is also able to sense human presence by detecting any motion such as a person walking and hand movements. This sensor can detect a presence up to 5 meters. In the low frequency band, X4M200 will operate within the 6.0 - 8.5 GHz band. In the high frequency band, X4M200 will operate within the 7.25 - 10.20 GHz band. The module is powered externally from either the USB port or an external power supply and the antennas are embedded onto the PCB. This XeThru device has data output similar to that of the goal for this project. The goal for this project is to have a device that processes respiration data in real time and to have a compact design.

V. CONCLUSION

The solution to non-contact vital sign detection is a rapidly developing field of research. In this project we were able to achieve two low-cost, low-power alternatives for detecting chest movement and vital signs of a still person. These experimental radar platforms will help to pursue research on vital signs detection at NIU.

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This project could not have been completed without the help of some very special people. NIU Senior Design Team 37 would like to thank Dr. Don Peterson who put great effort and dedication towards running the Senior Design projects, Dr. Veysel Demir for his invaluable technical insight and guidance, and Fahad Alqahtani, our teaching assistance, for his time and constructive feedback. Finally, Jeannie Peterson for her endless patience and making sure the team had all required materials.

REFERENCES


Infrared Based Interacting White Board

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Abstract—Despite a smart board’s ability to teach and demonstrate, interactive white boards are expensive by ranging up to prices in thousands of US dollars. Due to touching screens costing at high values, an alternative design could be created in order to reduce the price. The idea for the project is to use infrared based technology to transform a white board and projector into a distance based interacting white board. The project combines Arduino coding and an Infrared coordinates tracking camera in order to simulate mouse movement in conjunction with an Infrared emitting bar as a reference point. The handheld portion is simple to use and allows a wide degree of control from a distance in respects to the white board.

I. INTRODUCTION

Electronic Interactive White Boards are notorious for their prices ranging up to thousands of dollars with a variety of quality. This makes the decision of buying an interactive white board a tough decision. However, a cheaper alternative was created in late 2007 by a man named Johnny Chung Lee [1]. The Nintendo Wii Remote, fabricated by Nintendo, was created in 2006 to be used in point and motion-based games incorporating an infrared sensing bar [2]. Despite Nintendo’s insisted use of the phrase “Sensing bar”, this was nothing more than a ruse, as the actual sensing application lies within the tip of the Wii Remote [3]. Using the “Sensing bar” as a reference point, which has 5 infrared LEDs on each side, the infrared camera on the tip of the Wii Remote uses these LEDs as coordinates. Pointing the Wii Remote up gives the camera the impression that the LEDs are moving down. By inverting those coordinates, the Wii Remote signals the Wii Console to move the digital arrow in respects to the movement of the Wii Remote. The Wii Remote’s Infrared Camera is the key to Johnny’s design to create an interactive white board by using an IR camera and movable IR LEDs.

With the use of a different Infrared tracking camera and IR LEDs, the device needs to be designed to be easy to install and use on any white board with projector that is connected to a computer.

II. MATERIALS AND CODING

Which ever devices are used, the results need to fit within the palm of a human hand. The main component to create the baton is the IR Tracking Camera. It requires a 3.3V input and connects to the SDA and SDC ports of the M0 Feather Weight. The M0 was chosen due to its small and light size. Since the device should be wireless to gain use of the IR Tracking camera’s working distance of 3.3 meters, a blue tooth module was added to the design. A small battery along with a charger was incorporated within the designed for a reduced size and the ability to charge the device. Several push buttons are on the top shells to be used as left, right and middle mouse clicks. A power button is also on the top shell to turn the device on and off. The IR LED bar uses 100mA and 940nm infrared LEDs. Each side has 4 LEDs with a separation distance of 200mms. PCB board is powered by a cable and outlet combo to keep the LEDs powered. Each set of LEDs is powered by a 30-ohm resistor. Due to the limited amount of time, a covering shell was never created.

The feather weight, being an Arduino product, is programmed with Arduino based code. The code the device uses is from SAMCO [4]. The code uses various libraries in order to use the IR tracking camera and Absmouse for the coordinates to be translated into mouse movement. Due to the code being essential for the device, a link to the perfected edited code will be given via a link within the operator’s manual.

Fig. 1. IR Tracking Camera

III. PROTOTYPE DESIGN

As stated previously, the design must fit into the palm of the user’s hand. Right or left, it does not matter. The baton, which is now called the IR Remote, needed all the components to be arranged to retain a cylinder and prism hybrid shape. The battery and charger are in the far back of the shell. This allows an easy connection for the battery to the charger while also leaving the micro USB charger (USB type B) exposed. The very front of the design must be the IR tracking camera for the sake of pointing at the IR emitting
bar. A model of a human hand and other handheld remote
devices were used in the creation of the size and length of
the prototype in case for adjustments. Due to the odd shape
of the Bluetooth module, minor adjustments had to be made
in order the M0 feather weight can be placed directly on top
of it. The M0 needs to be directly connected to the Bluetooth
module through its TX and RX ports while also supplying
the device with power from the 3.3V port. The IR tracking
camera is connected to the M0’s SDA and SDC ports. The
M0 is also connected to the charger unit directly instead of
USB type A and USB type B connection in order to conserve
space. 4 buttons with the 4th one being a switch button is
used for the right, middle and left mouse clicks with the final
button being the on and off switch. Fig 3 being the prototype.

IV. DEMONSTRATION

Figure 2 demonstrates how the IR Remote operates. By
turning on the power button, the IR Remote sends out a
Bluetooth signal. The computer that can pair up with that
device will not be able to use the IR Remote until a code is
downloaded from the operator’s manual. The Projector that
is connected to the computer displays the monitor and placed
in the center of the projection is the IR emitting bar. The bar
is held up by either sticky tack or tape. If the board has a
metal sheet underneath, magnets should also be possible.
Regardless, the bar must be set in the center of the
projection. After the code is downloaded and ran, the IR
Baton now acts like a wireless mouse. By pointing at the
projection, moving left, right, up or down causes the mouse
on the computer monitor to move. Since the projector is
projecting the screen on the computer monitor, this simulates
movement. The best operating distance for the user is about
3.3 to 2.7 meters. The user does not have to be directly in
front of the board and can stand from the sides on a 23-
degree angle from the edges of the board. Clicking the left
button, preferable with the uses thumb or other index finger,
simulates a left mouse click. The right button simulates a
right mouse click. The middle button cannot act as a
scrolling wheel, but if held down, the user can point up and
down to move pages vertically.

REFERENCES

https://www.facebook.com/pg/samcolightgun/about/?ref=page_interna

V. ACKNOWLEDGMENT

Due to the events of this senior design semester, a
physical design could not be made. As students from NIU,
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Behavioral Tracking of Physical Activity in Small Social Rodents

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Abstract—Stress is an emotional or physical response that all humans will deal within their lives. There are different ways that humans will cope with stress, an example exercising. One way to study this phenomenon is to observe a group of homogenous mammals such as the prairie voles. Prairie voles are unique mammals that share social behaviors with humans such as living in family groups, forming social bonds, and they respond negatively to social stress. These rodents provide a valuable model to study the interactions of social behaviors and exercise in humans. The current laboratory setting consists two prairie voles in the same cage that mimic their natural habitat. The cage contains a running wheel with a cyclo-computer attached to measure the distance as the wheel is being used by the prairie voles. However, it does not differentiate between which prairie vole is using the wheel. Our device will differentiate between which of the two prairie voles is using the wheel at any given time and provide the data needed for further study. The device contains a Raspberry Pi 4 Model B that will have a Parallax RFID and a hall effect sensor attached to it. The RFID will identify between the prairie voles with a specific tag attached on them. The hall sensor is used to measure the distance that each prairie vole performs every time one of them gets on the wheel. The data will be collected onto a USB drive that is connected directly to the Raspberry pi. Ultimately, this device will provide critical data to the user with the knowledge of which prairie voles is being active.

I. INTRODUCTION

In everyday life humans experience stress. Stress ranges from different aspects of life whether it is from work, school, and even from everyday interaction with other people. This type of stress is called social stress. It refers to the strain that is formed from one’s relationships and social environment. It causes serious consequences on quality of life, emotion, and physical health. In fact, it is one of the most common types of stress in society.

A strategy to cope with stress is to exercise. Humans are complex and contribute to many factors that it is difficult to study how exercise benefits them. However, there are small mammals that share some attributes to humans. They are the prairie voles. These animals are monogamous meaning they form bonds that last their lifetime. More importantly, they crave social contact and when it is not presented to them, they become socially stressed. This makes them an ideal model to observe on a smaller scale. Dr. Angela Gripplo, from the Department of Psychology at Northern Illinois University, NIU, is researching how prairie voles provide valuable information on their interactions of social behaviors and exercise. Two prairie voles are put into the same cage with two running wheels. Then they are observed to collect the data needed. The data is to know when the prairie voles use the wheel, which of the two is using the wheel, at what distance did each traveled during the running session, and the total distance traveled in 24 hours. All this information was originally collected by someone constantly watching the prairie voles. This method would take up valuable time on research.

II. MATERIALS AND METHODS

The system is design around the Raspberry Pi Model B which is ideal to incorporate a Parallax RFID and a hall effect sensor because of its general-purpose input/output (GPIO). To identify the prairie voles, Parallax RFID tags are put on the voles with a collar. The use of the hall sensor will measure the rotations per minute (rpm) of the wheel which, with some simple calculations, can provide the distance traveled while running on the wheel. In order to implement these components, a design was built for the safety of the prairie voles. The cage and the running are provided by the client and this prototype was designed around. Fig 1 provides the assembled prototype; Fig 2 provides a close-up of the hall sensor (black component) with the magnet (red component); and Fig 3 demonstrates how the components are assembled.
The blue component is the RFID which is then set on the “Parallax Frame” (yellow component) which is 3D printed. This “Frame” is designed to have the wires feed inside of it to prevent the prairie voles from being exposed to the wires connecting the RFID and the raspberry pi. The green component is a “hall sensor guide”, which is also 3D printed, that helps guide the hall sensor to be away from prairie voles reach. It also provides a space at the bottom of the wheel for the RFID to fit. The hall sensor is attached to green component and needs to be close to the magnet to measure the rotations of the wheel (about 1” of clearance).

![Fig. 4. Circuit Diagram](image)

In Fig.4 the RFID power input (VCC) and Ground (GND) are plugged into the 5 volts and ground rails on the breadboard, respectively. We have an option to choose any of the GPIO pins for the /ENABLE, except the RXD serial port pin. We need the RXD to read data coming from the serial port. The wire hooked up to the SOUT pin runs through a voltage divider that will reduce the +5v coming out of the reader to around the +3v range that the RFID takes. You risk damaging your Pi if you put higher voltages than it is rated for into the GPIO. We used a 2200-ohm resistor and a 3300-ohm resistor which should reduce 5 volts down to about 3 volts. For the hall effect sensor, we have VCC running to the 3.3V source and GND running to the GND pin. The /ENABLE for the hall effect sensor can also go into any GPIO pin.

![Fig. 5. Data output](image)

B. Actual Results

The current results provide the user with the distance traveled each time the wheel is used. It will also output the total distance the wheel has accumulated throughout the day. Fig. 5 provides a sample data of testing this current prototype code which is access via USB storage device connected directly to the raspberry pi.

IV. Conclusion

This device is design to help our client, Dr. Grippo, to further study these interesting rodents. It would help quantify the information over a desired period. Unfortunately, due to the Covid-19 pandemic, resources and access to the prairie vole was limit or not accessible. However, there is a prototype code that could be tested at a future, more normal, time. The current code/prototype will provide the distance needed for further research.

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REFERENCES


Development of an Enclosure for Cryogenic Dark Matter Detectors excluding Electromagnetic Radiation

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Abstract — The goal of this project was to develop a platform capable of supporting multiple families of dark matter detectors, that was capable of greatly improving the amount of photon pollution within the enclosure as well as reaching cryogenic temperatures of 4 millikelvin. To accomplish this, copper was formed in such a way to thermodynamically assist in the cooling of the structure, while sealing in such a way that most of the noise would be attenuated by the enclosure.

I. INTRODUCTION

The hunt for dark matter is a new research field. In 1993 Fritz Zwicky was the first to realize the universe’s fundamental matter problem, although he referred to it as “missing matter”, not dark matter [1]. The discovery of the possibility of the “missing matter” was based upon astronomical readings of distant galaxies, where the amount of energy and matter within the system would not be enough to prevent galactic acceleration towards collision.

Most current experiments are searching for dark matter as a WIMP (Weakly Interacting Massive Particle), since observation of such WIMP particles, while requiring an extremely sensitive measurement system, is easier in the current universe than the measurement of axions. The measurement of WIMPs proves easier, due to the fact that they are massive particles, the odds of them passing through a detector is far larger than the odds of an axion passing through a detector. Combining the size benefit with the fact that weakly interacting particles intrinsically do interact with other particles on a certain level and scale, creates a unique opportunity to measure the event with a sensitive enough detector.

In order to accommodate such a sensitive detector, it is necessary to develop an enclosure capable of operating at cryogenic temperatures, that can absorb interfering radiation, and will not emit its own radiation. Such devices are not available on the current market as they must be designed for extremely particular use cases based on the available equipment of the operating laboratory.

II. MATERIALS AND METHODS

A. Design Requirements

First, the design must be able to operate at temperatures as low as 4milliKelvin. Additionally, whatever metal chosen that can handle the cryogenic cooling process to reach 4mK must also be minimally radiative in order to prevent the enclosure from creating its own noise pollution. Additionally, the enclosure must be made of a material with strong enough attenuation to limit the photon pollution down to one photon per hour. As the material prevents noise pollution from external sources, the internal parasitic resistance must also be dealt with by minimizing resistive sources and using materials that at cryogenic temperatures will become superconductors. Overall, the design must feature no more than 5 mΩs of resistance in total. The final requirement is that the enclosure must be sized proportionally such that 10-20 detectors can fit inside the cryostat unit, which can be seen in Figure 1, where the experimentation is conducted.

B. Manufacturing Methodology

In order to accomplish close packing, the hexagon-based design that was chosen required many sharp edges that are near impossible in standard manufacturing shops. One ideal method for cutting sharp corners is wire EDM. The vast majority of the enclosure design would benefit form using wire EDM, as wire EDM also allows tighter tolerances than milling, and features no constraints on the depth needed to be cut in the enclosure.

A secondary process that is planned to be used for the construction of the enclosure is CNC milling. CNC milling can be used to bulk remove the rough details of the enclosure, and with a proper CNC mill set up as seen in true industrial shops the majority of the design could be accomplished on a single mill. One large drawback of
milling the enclosure is the difficulty with modern mills to reach tiny features in deep cavities, as seen in the enclosure.

An overall constraint on the manufacturing process is the inability to make use of a cutting fluid, as the enclosure operates in a vacuum environment, should cutting fluid be used on the design a degassing event could take place and destroy the cryostat unit that is used to cool the enclosure.

III. RESULTS

Upon evaluating all material candidates that fit the design requirements it was chosen to use a high purity copper. As viewable in Figure 2[1]. It can be seen that the higher the purity the copper, the better the thermal conductivity at cryogenic temperatures, which are defined as temperatures below 123 Kelvin. The better the thermal conductivity, the better the system is able to transfer the heat out of the system at such a rate as to allow the enclosure to cool down evenly and avoid stress concentrations that could form cracks.

The second reason a high purity copper met the design criteria is that copper has one of the highest attenuation rates of all metals. In an ideal world lead would be used for the enclosure due to its ability to attenuate signals, however lead has both its own radiations, as well as a terrible thermal conductivity coefficient at nearly all temperatures. Copper, however, maintains an excellent attenuation rate, while allowing the thermal conductivity needed to cool the enclosure. The higher attenuation of copper achieves the goal of limiting incoming light pollution to one photon per hour.

The third and final reason for the choice in copper is its ease in machinability. Copper cuts very nicely and as a result as long as it is sufficiently cool it can be cut at almost any model shop. The ability to manufacture these enclosures at non-industrial model shops allows laboratories with minimal manufacturing abilities to manufacture their own enclosures.

IV. DISCUSSION

It is expected that when the enclosure is able to undergo proper testing at Fermilab it should be able to show a 100x improvement in preventing light leakage and reaching the desired one photon per hour noise level. Additionally, the enclosure should be able to handle temperature drops down to 4mK while maintaining electrical isolation, which in turn allows the greater than 100 Volt bias across the 4-millimeter detector, and disperse any heat generated by the internal electronics. Finally, testing is expected to conclude that 10-20 detectors can be installed onto the same plate within the cryostat unit.

V. CONCLUSION

In summary, in order to design an enclosure that can operate in the extreme conditions that must be used for the discovery of dark matter it is necessary to choose materials that allow for maximum performance. Figure 3 can be seen as the final design of the enclosure, showing not only the overall enclosure design, additionally the feedthrough methodology as well as the design feature known as the cassette.

VI. ACKNOWLEDGEMENTS

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VII. REFERENCES


Thermally Enclosed Phospholipid Enclosure

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ABSTRACT - Currently there is different research regarding the many different uses of phospholipids, including but not limited to increasing biocompatibility of foreign objects and new drug delivery systems. This paper describes a method for creating a thermally insulated enclosure in order to benefit the study of said phospholipid research. This enclosure will be portable, lightweight, and cheaply manufactured. There will be two main components to this enclosure that will be fitted together. The external thermal insulation layer is made of Nylon 6 and an internal conductive heating cell is comprised of Copper 110. This enclosure can be mounted onto the existing testing rig and will have its temperature maintained and monitored through an external PID controller to within 0.1°C.

I. INTRODUCTION

Phospholipids are composed of two parts, a hydrophobic and hydrophilic part. Due to the nature of these phospholipids, when they are placed in water, they create a membrane. These membranes can serve as a coating to make materials more biocompatible and can serve as a basis to drug delivery packages.

Dr. Lurio of the NIU Physics department is currently characterizing these membranes using x-ray diffraction through an aluminum observation cell. Dr. Lurio’s studies would benefit from a thermally controlled enclosure around this aluminum cell. Currently, the aluminum cell has a temperature gradient of just over one degree Celsius from edge to edge. The goal is to create a thermally controlled enclosure that reduces the temperature gradient to one tenth of a degree Celsius from edge to edge. The enclosure must be easy to use and come to a steady state temperature in a reasonable amount of time.

II. DESIGN

Some of the contextual knowledge used to approach this problem includes understanding different principles of heat transfer. Some of these principles include conduction, convection and radiation. It was these principles that were considered when creating the design for the enclosure.

A. Heating Cell

In the heating simulations without the enclosure, the observation cell could be seen to be losing temperature along the longest edge of the heating cell by conduction. To reduce this effect, all other available sides must be heated evenly to reduce the gradient along the longest edge of the heating cell. Using this conclusion, it became clear that an important property of the enclosure was to create a heating cell that evenly distributes the heat across the observation to maintain a minimum temperature gradient. In order to evenly heat all other available sides of the observation cell at the same time, an enclosure made of copper 110 is placed over the observation cell and mounts directly to the heated surface. The copper enclosure is heated by the mounting surface by conduction, then the heat is distributed to all available surfaces of the observation cell. Copper 110 was selected to be used as the material for the heating cell because of its high thermal conductivity and machinability. The issue we found with this design of the enclosure was that it would lose heat to its exposed surfaces by convection.

B. Insulating Cover

One of the issues found with this design was that there were flat surfaces on the outside of the heating cell that would cause heat loss by convection. The solution to this was placing an insulating cover over the copper heating cell to insulate the heat inside the enclosure. This cover would mount onto the heating cell with a single bolt and would be made from nylon 6. Nylon 6 was selected because of its very low thermal conductivity and minimal cost.

![Phospholipid Bilayer](image)

Figure 1: Phospholipid Bilayer

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III. EXPERIMENTAL

A. Simulation

In order to produce the most accurate results, this project's goal was to create an enclosure that would maintain the fixture's thermal gradient to 0.1°C.

The goal of the first simulation was to replicate the environmental conditions on Dr. Lurio's lab. Doing so would create an understanding of the current temperature distribution inside the observation cell. In order to obtain some of the parameters for testing, convection coefficients must be calculated. The convection coefficient was calculated by using similar heating scenarios found in the fundamentals of heat and mass transfer book. Then the observation cell was then treated as a fin with regards on thermal analysis. After applying the calculated convection coefficients, a 3-D Model was crafted in Autodesk Inventor and imported into ANSYS Steady-State Thermal. Using ANSYS, it was possible to apply calculated parameters as well as experiment with different heating element placements across the fixture. After various simulations, it was identified that the gradient was the lowest when the observation cell was heated at both ends using conduction, while all other available surfaces were heated using convention.

B. Results

As shown in Figure 4, after implementing the environmental parameters that the observation cell would be experiencing while inside the enclosure, it was found that the cell would have a temperature gradient of less than a tenth of a degree Celsius. While there appears to be the same amount of thermal gradient on either figure, the temperature change is quite drastic. In figure 3, the overall temperature loss was 1.16°C whereas in figure 4, the overall temperature loss was 0.06°C.

C. Testing

After manufacturing the enclosure out of the respective materials, it will be further tested through running a live experiment. There will be an additional hole milled into the top of the enclosure to allow thermistors to enter various points along the test fixture. This will allow for the monitoring of temperature distribution across the system. This is how the temperature gradient will be confirmed across the observation cell.

IV. CONCLUSION

Overall this project focused on creating an enclosure that maintains the temperature around and inside the designated fixture. Through the help of PID control and computer simulations, it was possible to verify that using the thermal enclosure, the temperature gradient was maintained and controlled to within 0.01°C. Upon completion, this project will assist in the research of phospholipid structures for Dr. Laurence Lurio.

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REFERENCES

Integration of a NAO Robot with an Autonomous Mobile Platform

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Abstract—This project strives to create an autonomous vehicle using Raspberry Pi and various other items. This vehicle is linked with a NAO robot in order to create a tour experience for visitors and students of Northern Illinois University. The tour is completely automated, negating the need of a human tour guide effectively saving the university time and money.

I. INTRODUCTION

The NAO robot is an advanced piece of robotic hardware. It is capable of speaking, listening, walking, and much more. With the NAO robot being as sophisticated as it is, giving it a human job is not an issue. One possibility is a tour guide. This robot could serve as a great tour guide. It could self-navigate based on visual signs, speak to the guests following it, and potentially answer questions. However, the NAO robot falls short in the category of walking. It is very capable of walking itself around but does so at a very slow pace. At the speed it walks, a tour of a single building could take much longer than most people would prefer.

The inability of the NAO robot to maneuver quickly around the building is where we derive the purpose for our project. We seek to design a device to transport the NAO robot so that it can maintain the human walking pace of around three miles per hour. In addition, we seek to design a meaningful robot human interface to make receiving a guided tour for a small robot a natural experience for the average person.

II. ELECTRICAL DESIGN

A. Motor System

The motor system is the driving force of the vehicle. The motors chosen for this project are the 12V DC 437RPM 305.5oz-in HD Planetary Garmotor from ServoCity. Four motors are used in total, one for each wheel. It is capable of rotating at a speed of 437 rotations per minute. This is more than enough to get the platform moving at a normal human walking speed. The maximum torque is 305.5 oz-in. With four motors, this is able to move more than twice the weight of our platform fully loaded. The required voltage is 12V. The rated-load current is 2A with a stall current of 20A.

The motor driver used is the Cytron MDD10A motor driver. This driver takes in 12V directly from the power supply in order to power itself and the DC motors. It is capable of outputting 10A of current continuously with a peak of 30A for ten seconds making it a good fit for the motors. As there are four motors on the platform and the drivers are dual-channel, there is a need for two drivers. One controls the two front wheels and the other controls the two back wheels. The drivers take four logic level inputs (two from each motor) from a Raspberry Pi in order to control the speed and rotation of the motor.

B. Power System

In order to power the NAO Vehicle, a 12V, 142-Watt Hour lithium-ion battery will be used. This rechargeable battery was selected due to its long running life, and low cost. The four motors, the two motor controllers, and the Raspberry pi will all be powered by the battery pack. These loads will draw a maximum of 20.64 A of current.

III. MECHANICAL DESIGN

The chassis of the vehicle is comprised of four 80/20 1010 series 6061 aluminum bars, connected using 80/20 end fasteners (Fig 1.). This will ensure a rigid, light weight, low cost chassis. In order to mount the wheels and motors a bracket was custom fabricated out of 2024 high strength aluminum 90-degree angle (Fig. 1). This bracket allows a high weight tolerance and a rigid suspension. The wheels selected for this vehicle are 100 mm Mecanum wheels (Fig. 1). These wheels allow the vehicle to not need a steering system while also allowing directional turning at full speed. The electrical controls are mounted on a 4.75 mm thick acrylic sheet insulated with Garolite spacers (Fig. 1). The vehicles platform is also 4.75 mm thick acrylic mounted with a Flat head screw and 80/20 drop in nut (Fig. 1). The Acrylic gives the vehicle an electrostatic resistant material that is very strong and low cost.
IV. SOFTWARE

A. Image Processing Algorithm

The image processing algorithm is the driving force behind the navigational decision making of the vehicle platform. It receives images from an onboard camera as an input. This input is processed to find a line on the ground in front of the vehicle. It then outputs a difference from center value that instructs the motor control algorithm which way to actuate the motors.

In addition to providing navigational instructions, the image processing algorithm also senses QR codes within each frame. These codes are used as cues for the NAO robot to talk about each room he passes on the tour.

B. Motor Control Algorithm

The motor control algorithm is written in Python and utilizes the gpiozero library to control the I/O of the Raspberry Pi. The algorithm receives a number passed from the image processing algorithm. The value of the number is between -1 and 1. Based on the number received, the algorithm decides how to set the speed of the motors in order to keep the vehicle on the track.

C. Depth Sensing Algorithm

The depth sensing algorithm is written in Python and utilizes many libraries in order to function properly. The libraries are OpenCV, Numpy, and RealSense. The algorithm works with the Intel RealSense D435 Depth Camera. By using the preset functions from the libraries, it can return the distance in meters of the center pixel of the image. It is planned to be used with an object detection algorithm in order to tell the vehicle if it needs to be stopped due to an object or person in the way.

V. CONCLUSION

This paper presents the progress made on this project by the end of the academic year. Through the resources provided, a theoretically working vehicle has been completed through software simulation. Due to unfortunate circumstances, the real testing and final product were not able to be seen as it was not possible to meet as a team for the second half of the spring semester.

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The Second Generation Smart Handle
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Abstract - The smart handle is designed to be a Human-Machine Interface (HMI) specifically designed to be used with exoskeletons but could have applications to control other pieces of complex machinery. This second-generation design fixes key design flaws of the first and explores different ways of achieving the same result—a handle that can detect the forces applied to it and transfer it as data to a neural network. The first generation used linear strain gauges along segments of a segmented handle, this generation will focus on triaxial force detection from pieces on the top and bottom of the handle that deform when forces are applied to the shaft. There are two prototypes designed that fit this definition of the second-generation smart handle. These two designs cover two routes the smart handle can follow, one of high quantity data collection and one of minimalist data collection.

I. INTRODUCTION

With the advance of technology, ways of controlling that technology get more and more complex. People try to simplify the control of innovations with the use of Human-Machine Interfaces. HMIs can be complex themselves, so much so that people must learn or get certified on the use of them, such as for aviation controls or crane operation. Many HMIs are designed to be simple themselves, to make the use of these complex machines more straightforward. HMIs cover a vast spectrum. They could be levers, switches, computers, tablets or even other more innovative devices.

The smart handle’s goal is to be an innovative HMI that is intuitive in its use. Ideally, the smart handle would be used to control upper extremity exoskeletons, but it has the potential to be applied to many different pieces of machinery. The smart handle will be gripped by the operator; when he or she attempts to move the smart handle, they will apply forces on the handle that the handle will identify. The smart handle, working in conjunction with a neural network system, will interpret the force data that the operator applied. It would be able to ascertain how the person wants to move the handle. If the handle detects vertical forces, the network will know the person wants to lift—or lower—the handle. In addition, the neural network would identify the method in which the forces were applied, such as elbow flexion for a lifting and pulling force. Using this information, the system could then reflect that movement to the connected machine.

II. PROTOTYPE DESIGNS

A. Strain Gauge Design

The strain gauge design uses 48 strain gauges positioned at key points of the physical model in order to detect how the material deforms in those areas. The strain gauges used in this design are linear model strain gauges (1033-MMF404326-ND, Micro-Measurements, Raleigh, NC). They were chosen to be used mainly for their high strain range and size. These gauges are applied onto the top and bottom base pieces of the model, with 2 gauges on every face of the connecting pieces. The gauges on opposite sides of each connecting piece are grouped together into a single full-bridge Wheatstone bridge circuit which acts as a single data point. This results in 12 Wheatstone bridge circuits returning 12 real-time data points for the neural network to read.

The physical model for this design was made with this base piece in mind. By affixing the center of the base piece to the handle while holding the outside ring of it in place, the connecting pieces can experience micro strain that describe the force put on the handle.
By comparing the data gained from all 12 data points, the neural network would be to ascertain a detailed description of the strains caused by the forces put on the handle, and then describe the motion enacted upon the handle that caused the forces.

**B. Pre-Made Load Cell Design**

The load cell design is another triaxial based design, but instead of a hand machined base piece to experience strain from the user-applied forces, it consists of six single-axis load cells—two sets of three—aligned ninety degrees from each other to simulate two triaxial load cells attached to the top and bottom of the handle. The load cells used in this design are S-shaped load cells produced by CALT: DYLY-103-50K (CALT, Nanyuan, China). These load cells work in tension and compression, allowing them to give positive and negative values so that the neural network can differentiate between pushes and pulls. By comparing the values obtained, similarly to how it is calculated in the strain gauge design, it can determine the direction of the intended force.

**III. ELECTRICAL DESIGN**

Fig. 3 Model of the electrical circuit

Both prototypes use similar electrical designs to translate the data gathered from the load cells/strain gauges into the neural network system. They are both routed to Wheatstone bridge circuits—one particularly suited to force determination—before being amplified and sent to the Arduino MEGA as an analog input. From the Arduino MEGA (Arduino, Scarmagno, Italy), the data is processed and sent via USB to a computer running LABVIEW (National Instruments, Austin, TX).

Fig. 4 Block diagram of the system

The main focus of this design was to allow the force data obtained to be compared against force patterns for types of motion that the user’s hand would initiate. These patterns would have to be determined prior to the comparison, but once obtained would allow the smart handle to determine the intended motion of the user and actuate upper body exoskeletons to affect this motion.

**IV. CONCLUSION**

These two designs explore different ways to expand the concept behind the first-generation smart handle. The load cell design shows promise in its simplicity and lower amount of data while the strain gauge design offers greater functionality at a greater cost to construct and a significant amount of data.

**V. ACKNOWLEDGEMENTS**

We would like to thank Hasan Ferdowski and Simon Kudernatsch, our faculty advisors. We would also like to thank German Ibarra and Donald Peterson for their contributions.
Lever Aid for Enhanced Wheelchair Motion
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Abstract—This document outlines the principles utilized in the design of a lever operated motion mechanic for a wheelchair. A lever attachment adds an additional method for propelling a user operated wheelchair with less applied force.

Keywords- Design; Mobility; Muscle; Wheelchair

I. INTRODUCTION
Technology with regards to wheelchairs hasn’t changed much over the course of several years. Quickie wheelchairs have become the most popular model of wheelchair across the young generation of wheelchair users. This generation of users will want to go to more places than the standard chair is currently capable of. A lever assisted motion mechanism can make this possible. One main drawback of the current design of a wheelchair is the method of motion. By reaching to the outside of the chair, the user is utilizing a weak muscle group repeatedly to make the chair move. This cyclical motion wears the operator out in a concise period of time. The rate of exhaustion is exponentially increased when the terrain becomes rough. The solution to the problems mentioned above lies in transferring the load of the chair and the operator’s weight to a more dominant muscle group, namely the bicep and pectorals. The most efficient resolution is a lever extending upward from the wheel axle and parallel to the users arm extended perpendicular from the body.

II. ENHANCED MOBILITY
To achieve a higher level of maneuverability the lever is built into the armrest of the chair complete with a joint that folds the arm into the 90° position for stationary use as shown in Figure 1.

The first action the user needs to complete to move the chair is to squeeze a lever similar to the brake handle to engage the grip arm to the pulley wheel, similar to gripping the outer rim of the wheel to move the chair. After the grip is established on the pulley wheel, the user can move the chair by pushing perpendicular to their bodies.

A. Equations
The first engineering principle at play is the moment equation for force applied at a distance (Equation 1),

\[ M = Fd \]  (1)

Where \( M \) indicates moment, \( F \) indicates force and \( d \) shows distance to the center of rotation or in this case, the axle. Because the wheelchair’s new lever arm will extend a distance 50% larger than the outer rim of the wheel, the value of applied force will be greatly reduced. A low value of means a lower rate of exhaustion for the user. The low force value works in conjunction with the larger muscle group and makes for an overall much more comfortable user experience.

The gripping mechanism provides an additional function to the chair which is braking. A critical factor in braking is stopping distance which is calculated with Equation 2.

\[ W_{friction} = \mu mgd = \frac{1}{2}mv^2 \]  (2)

Using general wheelchair speeds and average mass values, an average stopping distance of 1.8ft was established for this chair configuration.

Figure 1. Side view of the chair in operation.

Figure 2. Isolated lever view.
III. MATERIALS

The optimal material for the lever would be alloy steel or a material that can withstand a lot of wear and has a high yield strength, but this material is mainly reserved for high power transfer. The lever can be expected to have a small to average power transfer, so the material that is practical for the lever would be a soft metal like aluminum or bronze. Aluminum alloys are widely used in manufacturing when a light weight, moderate strength and corrosive resistant material is used. 6061 aluminum alloy is one of the most common aluminum alloys used for engineering, it has an ultimate tensile strength of about 42000 psi and works best with this design. 6061 aluminum alloy is mainly composed of aluminum but is mixed with elements such as magnesium, silicon, iron, copper, manganese, chromium, zinc, titanium, and other materials that make up a very small percent of the alloy.

IV. PROTOTYPE TESTING

A. Prototype 1 (Ratchet)

Going into the Prototyping stage of this project was a big tuning point. The team initially began this project with a ratchet like design made of wood. The ratchet would interface with the spokes of the wheel and connect to our center brackets of aluminum. The pawl (ratcheting mechanism) for this ratchet design would then be kept in tension against the gear with springs that connects to the housing. The housing had a telescopic connection with the collapsible lever. It was soon discovered, however, with this design the shifting would be the most difficult part of this project. During this stage in the design the shifting mechanism had to be redesigned in order for the wheelchair to move forwards and reverse.

B. Prototype 2 (Pully and Belt)

After rethinking the shifting mechanism, the team came up with a new design that would help with the shifting. The team developed a new prototype with a belt and a pulley. The belt looped around the pulley and tightened depending on how the bracket was tilting. The bracket connected both ends of the V-belt and could tilt about its center. This tilt would create different tension points depending on its angle. The idea came from a tension wrench for an oil filter. Although this was a new design the problem still lied with the shifting. In theory it worked, however, with the resources at hand it could not produce the outcome needed to shift the bracket.

C. Prototype 3 (Clamp Design)

The final design was a clamp like mechanism that would use the belt and pulley from our previous design. The belt was cut into strips and placed in a “C” shaped piece of aluminum. It would then tighten by a cable, closing the “C” shaped clamp causing there to me more surface contact between the pully and V-belt. The cable would be engaged by a lever at the user’s hand towards the end of the collapsible levers.

V. WEAR AND MAINTNANCE

The wear on this system will mainly come from the band. In the best case the band lining would be sold separately as needed. The replacement of the belt could be done easily by the user with little to no help. Another area for wear would be the hinge that allows the lever to bend 90 degrees. The hinge would be used constantly and since the components of the hinge are small, they are likely to wear more. Also, a bike brake that will be used the most to engage the cable at every push, little to no maintenance will be needed for the brake handle.

VI. CONCLUSIONS

A new lever wheelchair allows a user a more complete experience by permitting them to go farther and to more locations. This inexpensive attachment will be available to any customer at any time to act as an upgrade to their existing chair. Most EMW options are available only with the purchase of an entire chair making this option by far the most economic choice.
Prototype Electric Vehicle Phase II

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Abstract—The primary purpose of our project was to continue the development of the benchtop prototype electric vehicle through the application of a bi-directional converter which drives an electric motor using a battery pack. The key features of our project are as follows. There is a bi-directional converter which boosts and bucks voltage to transfer energy between the batteries, motor, and capacitors. The client will use a terminal to control the motor speed and be notified of measurements and fault-conditions associated with running the motor. The design chosen to control the bi-directional converter uses Proportional-Integral (PI) control. This was implemented with an Arduino microcontroller and an analog voltage sensor. The motor drive is inputted with DC from the converter and outputs three-phase AC to run the induction motor. The finished project is able to turn the motor using the battery with proper communication from the Arduino in order to do so. This project will give a future prototype electric vehicle team the opportunity to further develop this design.

I. INTRODUCTION

The main part of this project is the bi-directional converter. This converter is a combination of a boost and buck converter circuit. A boost converter is created by connecting an inductor, IGBT (insulated-gate bipolar transistor), and diode. When the IGBT is turned on, the current builds up in the inductor. When turned off, the current is released from the inductor through the diode to the capacitor and load. A buck converter is created by connecting the same components in a different manner. When the IGBT is turned on, current flows through the inductor. The inductor should be large enough to maintain continuous conduction for the load. This means that when the IGBT is turned off, current will continue flowing to the load (i.e. the voltage source) by looping through the diode.

Figure 1: Bi-directional converter schematic

The bi-directional converter, Figure 1, is created using the same circuit as the boost converter apart from replacing the diode with a second IGBT. The boost converter portion is controlled using the PI method. A block diagram of this controller can be seen in Figure 2.

The Discrete PI Controller block uses the backward Euler discretization method to calculate the control signal $u(k)$ as shown below.

$$u(k) = \left[K_p + (K_i + du(k)K_{aw}) \frac{T_s}{z-1}\right]e(k),$$

where

- $u$ is the control signal.
- $K_p$ is the proportional gain coefficient.
- $K_i$ is the integral gain coefficient.
- $K_{aw}$ is the anti-windup gain coefficient.
- $T_s$ is the sampling period.
- $e$ is the error signal.

II. MATERIALS AND METHODS

The boost part of the bi-directional converter was simulated with Mathworks Simulink. This was accomplished by drawing a boost converter with a PI controller in Simulink as shown in Figure 4. The implementation and equation shown in Figures 2 and 3 were included in the Simulink schematic via the Discrete PI Controller block. The output waveform of the boost converter is analyzed in the Results and Discussion section. The actual boost converter controlled by the Arduino microcontroller, using the PI control method, that drives the motor with the battery supply voltage is discussed in the next paragraph.
It was possible to implement a tunable PI controller using the Arduino programming environment. Figure 5 shows an excerpt of the implemented code. The first three lines are from the top and control the setpoint for voltage (s), proportional constant (Kp), and integral constant (Ki). Lines four through eleven are from the main program loop. Line four reads and scales the measurement from the voltage sensor (Figure 6). Line five computes the error between that measurement and the setpoint. Line six adds that error together which accomplishes continuous integration. Line seven limits the error to ±10000. Line eight computes the control effort by multiplying the error by Kp and the accumulated error by Ki. Line nine limits the output duty cycle to 210/255 to avoid damaging the IBJT. Line ten writes the output value to the PWM pin. Line eleven toggles an output pin which when connected to an oscilloscope can be used to verify the integral step size is constant. When looped continuously, this program performs the function of a PI controller.

III. RESULTS AND DISCUSSION

The Simulink simulation of the boost converter with PI control yielded an output voltage with 0.2% error and a ripple voltage of 1.5 mV. The actual boost converter yielded results within a couple of volts of the setpoint with little ripple voltage. Figure 7 shows how the output voltages for both the Simulink simulation and the actual output measured on the oscilloscope have the same sawtooth waveform pattern. This confirms that the actual PI-controlled boost converter operates like the one simulated in Simulink.

IV. CONCLUSIONS

Development for the bi-directional converter included implementing boost functionality to run the motor. PI control was used and implemented using MathWorks Simulink and the Arduino IDE (integrated development environment). The issues encountered during development, including those involving the Arduino communication and reset cycle, were solved. Documentation has been left for future development work on the Prototype Electric Vehicle.

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REFERENCES

Autonomous Vehicle Lateral Control System

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Abstract—The goal of this project is to create a lateral control system that enables a self-driving car to safely switch lanes with full independence. Its uniqueness originates from the project’s cost-effectiveness and its ability to be tested on a college campus. These aspects are desired as the project has the potential to be scaled to full size vehicles and to expand the research and development at Northern Illinois University.

I. INTRODUCTION

Autonomous vehicle technology has been in development for the past twenty years. Over these two decades, the technology has significantly improved [1]. Despite the advance of autonomous function in vehicles, total lateral autonomy in vehicles is yet to be seen. Therefore, detailed research into the design and fabrication of highly autonomous vehicles is a growing field. Simplistic lateral autonomous systems have been developed but do not allow for safe lane changing as their algorithms never meet their safety requirements for a lane change. More complex solutions take too much time to compile data, thus making them useless [2].

A system that authorizes autonomous vehicles to safely and successfully switch lanes must be established to continue progress in autonomous vehicle technology. This project developed such a system and proposes a lateral control system that allows for a virtual simulation of vehicular lateral autonomy. The lateral control system is cross compatible to physical vehicles.

Two distinctive qualities of the project stem from its ability to be tested on a college campus and its efficiency in terms of cost. These attributes are preferred when a project has the aims to be scaled to full-size vehicles and to evolve the research and development at Northern Illinois University (NIU), as this project does. The full-size scalability realizes the autonomous vehicle industry’s demand for a solution to the lack of safe and effective lateral control systems.

Additionally, NIU is able to have an impact in the automotive industry if research in the area of self-driving cars is cultivated and refined at the university. Research and design throughout the project yielded a virtual simulation of an autonomous vehicle lateral control system that serves as a foundation for future researchers.

II. METHODS AND MATERIALS

This project utilized an array of sensors consisting of a tracking camera, a depth camera, a LIDAR (Light Detection and Ranging), a powerful processing unit, and an open source electronic speed controller. The T265 tracking camera and the D435 depth camera are both a part of Intel’s RealSense technology line. The tracking camera was chosen for localization. It uses Visual Inertial Odometry Simultaneous Localization and Mapping (V-SLAM) to know its location with respect to the surrounding environment. The depth camera was chosen for its ability to identify lane lines and aid in lane keeping. It can also support object detection by knowing the depth of objects, or how far away the object is from the camera. The Slamtec RPLIDAR A2M8, with its 360° angular range, was the primary object detection sensor selected due to its impressive range of vision.

A formidable processing unit is critical to the project. Without this piece of hardware, the necessary calculations from the algorithms responsible for lane changing, lane keeping, and object detection would not be possible. The NVIDIA Jetson TX2 was picked for its abilities to do just that. Its relationship to the other sensors is detailed in Fig. 1. Additionally, to effectively test autonomous technology on a remote-controlled (RC) car, the vehicle must move at slow speeds. An open source electronic speed control, or VESC, allows for the selected processor to take full control of the

Figure 1. A block diagram illustrating the sensors and processor for the system and their functions.
vehicle’s motor. This will allow the vehicle to move as slowly as needed during testing.

Due to physical limitations in early 2020, these pieces of hardware are being represented by CARLA, an open source autonomous vehicle simulator. This simulator enables a theoretical application of a longitudinal and lateral control system that allows for both autonomous speed control and lane changing.

III. RESULTS AND DISCUSSION

Through the CARLA simulator, an abstract application of imaging sensors, a LIDAR, and a processor were achieved. This application was a longitudinal and lateral control system created via python scripts. These control systems enabled lateral autonomy, lane keeping, object detection, and object avoidance. Both the lateral and longitudinal autonomy of the virtual car were established through two independent proportional integral derivative (PID) control scripts. These control scripts operated on data made readily available by the simulator itself. In the case of the lateral PID controller, the error was determined by extracting the location of the center of the lane and comparing it to the location of the center line of the virtual vehicle. This difference was then fed into the PID script as the input. The output of the PID script aided with steering, thus enabling fully autonomous lane changing. The path that the virtual car took is overlaid on the desired path in Fig. 2.

Not only was full lateral autonomy and lane keeping achieved, but object detection and avoidance were also implemented into the lateral control system. Through the Carla simulator, stationary vehicles were generated. The autonomous vehicle had its onboard sensors detect how far the stationary vehicles were away from it. When the distance reached a certain threshold, the autonomous vehicle initiated a lane change to an open lane. This resulted in a smooth path of travel for the virtual vehicle despite obstacles being randomly generated by the simulator.

IV. CONCLUSIONS

This simulation, being the theoretical application of hardware, allows for easy implementation of an autonomous lane changing algorithm to real vehicles at different scales.

Not only will the lane changing algorithm be able to give differently scaled vehicles the ability to switch lanes autonomously, but it will also enable them to detect obstacles and avoid them via autonomous lateral movement. Furthermore, the objects were avoided in an efficient manner without giving up the consistency of the vehicles path of travel. Given these two products, this control system has expanded the research and development of autonomous vehicles at NIU. It will permit the next group of students to continue to make an impact on the future of autonomous technology at NIU and be in the forefront of innovation within autonomous technology.

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REFERENCES

Automated Torquing Cell
for Jeep Cherokee Trans Bridle Assembly

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Abstract— Autonomous assembly is the driving force for humanities fourth industrial revolution. Android Industries assembles engine for Jeep in Belvidere, Illinois. Android Industries strives to increase efficiency without sacrificing the health and safety of its employees. Automation on assembly lines is the means of meeting the ever-increasing consumer demands. Employees working on assembly lines often experience ergonomic issues in their joints caused by repetitive motion and forces transferring through their body. Android Industries requires an autonomous torqueing cell to accomplish the repetitive tasks, increases the quality and repeatability of the work, while also mitigating the harm to the workers. The Torquing cell was designed and prototyped in SolidWorks before being manufactured and implemented into Android's existing systems. The cell is pneumatically driven, controlled by a programmable logic controller. The design features three subassemblies: the motion mechanism, the control system, and the support structure.

I. INTRODUCTION
Android Industries requires the torqueing cell to perform the final torque attaching a bridle to the engine mounting bracket. The automated torque cell is designed to torque a specified bolt without the interaction of a human operator. The auto torque cell containing a DC Nut-runner positions itself in the correct orientation and drives a fastener to final torque value. The auto torque can torque bolts for three different engine models on multiple planes and angles. This auto torque cell design includes three major sub-assemblies: the motion mechanism, the control system, and the support structure. The divisions of the torque cell coincide with the manufacturing process. The motion mechanism is fabricated and assembled, followed by the control systems for testing and optimization, while the support structure is assembled at the location for implementation.

II. DESIGN FEATURES
A. Motion Mechanism
The motion mechanism of the automated torquing cell is the DC nut-runner assembly. This DC nut-runner assembly is made up of off the shelf components with custom made brackets attaching them together. The use of off-the-shelf components allows Android to easily replace broken or worn-out parts rapidly. The brackets that were designed to use readily available materials sizes to reduce the amount of machine time, this reduces downtime of the mechanism and complexity. The main component of the DC nut-runner assembly is the linear bearing slides these linear bearing slides allow the nut runner assembly to have smooth movements resulting in a long service life. The movements of the assembly are accomplished using pneumatic cylinders. By using pneumatic cylinders, the assembly can have rapid movements and part commonality with Androids’ other machines. Shock absorbers are used to slow the assembly down, when it reaches a position. This reduces stress on the components of the assembly and leads to longer service life.

B. Control System
The system is controlled by a programmable logic controller (PLC) using RLS Logix 5000 version 19. Androids System communicates directly to the controller housed in the control box. The control box contains the PLC, the power supply, an air manifold with a series of two-way air solenoid switches, relays, and circuit breakers. The PLC receives signals from Android indicating which engine model is currently in the station and determining which of the three programs to run. The PLC sends a signal to the Nut-runner to begin spinning and moves to align the Nut-runner with the bolt on the engine model. Induction sensors

Figure 1: SolidWorks Model of Auto-Torque Cell
attached to the air cylinders indicate the location and authorize the movement of the Nut-runner towards the engine. The Nut-runner sends the value of the torquing and indicates whether the bolt is torqued to the proper amount or not. The completed torque signals for a systematic retraction of all the pistons, and the PLC indicates to the status to Androids Industries system and workers in the area via a stack light.

C. Support Structure

The support structure is made of 80-20 Aluminum and is designed to seamlessly integrate into androids existing support structures. The structure was designed to ensure maximized adjustment to the range of the hard stop. The support structure holds the motion assembly above the engines as they pass through the station. The Support structure also holds the control panel for easy access to the wiring adjustments to the programming and wiring. All wires and tubes run safely along the support structure in cages and are secured with zip ties.

III. IMPLEMENTATION

During the design phase, adjustments were made to utilize materials that were available at Android Industries as well as to match the fabrication methods already in place. The original PLC was replaced by an older version that was compatible with the version of the RLS Logix was licensed to Android Industries. Many of the switches, wire busses, and relays were pulled from Android Industries extra supply stock.

The Torquing Cell was delivered, and the support structure was assembled at Android Industries. The support structure required significant adjustments to ensure that it did not interfere with existing sensors while still maintaining all clearance requirements and maximum adjustability.

The largest challenge with this project came with the shelter in place order issued due to the COVID-19 pandemic. Android Industries shut down due to the virus and did not allow for visitors. Engineers at Android Industries [1] were able to finalize all wiring and adjust the program to integrate with their systems properly.

The Automated Torqueing Cell is fully functional for all three engine models and has been tested during the extended plant shutdown. However, the cell will not be optimized until the production restarts, and live testing opportunities become available.

IV. CONCLUSION

The new Automated Torqueing Cell ensures that the bolts are tightened to the specific regulations improving the quality and repeatability of the station it replaces. The new cell allows for Android Industries to reduce the ergonomic issues experienced by workers performing repetitive tasks by allocating the replaced manual labor to perform more complex tasks.

The new Automated Torqueing Cell increases the efficiency of the Android’s assembly line, improving their on-time delivery and production efficiency.

ACKNOWLEDGMENT

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REFERENCES

1. Allen Bradley
Thermal Interface Test Apparatus

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Abstract - A device to study the effects of heat transfer across a thermal interface material that would simulate real life conditions. This device was designed to function as a test platform that would reduce time and cost of testing out difference thermal interface materials that would ultimately go in and function within the Variable Frequency Drives that Danfoss manufactures. This device records all the data it collects and thus can be used to help make better models of what is happening inside of the device when in operation. This allows Danfoss to better simulate what is going on inside of their drive’s and determine if maintenance must be done to the drive to continue its operation. This test apparatus will be used to test different thermal interface materials to help better understand their properties and performances in a more realistic sense and not just relying on the data sheets of the thermal interface materials for their data.

I. Introduction

Danfoss brought forth the table a problem with heat management, specifically heat dissipation through a Thermal Interface Material (TIM). Danfoss has been having issues with their Variable Frequency Drives (VFDs) failing earlier than expected and they have deduced it is because the TIM material being used is not performing as expected. This is the primary motivation behind the project that Danfoss has proposed, how to measure the temperature difference across the TIM material.

II. Materials and Methods

The key components to the project that would resemble a VFD are the heat sink and more importantly the insulated gate bipolar transistor or IGBT for short. The IGBT is where a VFD gets its power from. The TIM material is between the IGBT and the heat sink. To be able to find the TIM materials thermal conductivity a temperature measurement must be taken across the TIM. To do this, J-type thermocouples were chosen. By setting up thermocouples on the IGBT and on the heat sink, the temperature difference can be measured across the TIM. Finding this temperature difference allows us to find the thermal conductivity of the TIM.

Another section needed in this project is a cooling system. An effective cooling system is required because when powering an IGBT temperatures become extremely high. In order to be able to test multiple TIM materials effectively the system needs to be cooled as soon as possible so the next test can start. To meet these expectations a fan cowling was designed and 3D printed. Danfoss provided us with a fan that they currently use for cooling that has a high RPM. Another small task that had to be designed and 3D printed was a box for the top of the heat sink. The box was designed to help simulate how much space is within a VFD between an IGBT and its walls and how the heat will be contained within. This box more importantly covers the aspect of safety in the device, because the box will block any contact between a user and any person or bystander from the heat transfer from the IGBT to the heat sink. The box also allows for the small thermocouples to go into their respective spots across the IGBT and heat sink.

A final requirement from Danfoss was the device needed to have a GUI, a graphical user interface that would be used to control the device. This was done using the program called Processing because it allows for easy communication between the Arduino and the computer hooked up to the device. Using Processing, the user will use the GUI to talk back and forth with the Arduino to control the apparatus and show test results from the tests that are run.

III. Results

To gather the main data such as the temperatures and current measurements, 2 systems were developed. For the temperature, thermocouples connected to a serial hub then converted from a RS485 signal to a signal that an Arduino mega could read. Though mostly a coding endeavor, the final outcome was accurate and responsive temperature readings in real time when two thermocouples were placed in different temperature environments (i.e. ice water and boiling water). Scaling up was as simple as adding additional lines of identical code. For current measurements a transducer connected to the Arduino was tested. Functionality without having an actual 500-amp supply proved tricky initially, however a “trick” was worked by making several windings to
the transducer simulating high current using a standard lab bench supply. Several trials were run, and a curve was plotted that showed very close measurements to that of the data sheet, confirming system was functional.

In conjunction with a heat sink, a variable speed fan controlled via Arduino was used. The speed control was proved functional by coding implementation via a relay and its PWM pin. This allows the user to ramp up the fans or automatically run the fans while testing the user interface. Different speeds were tested and successfully adjusted remotely.

Unifying all the data and control was the coding behind this project. To ensure a user-friendly experience a user interface was developed to see the output data. Below in Figure 1, is an image of the completed GUI that allows for the user to interact and control the thermal test apparatus that was designed. Seen here is an example of thermocouple data and test stand control along with the ability to name tests and control the fans. This is only one of the many modular options a person running a test could display. Lastly, the mechanical layout created deemed the most efficient.

In Figure 3 above, this is the final agreed upon layout of the designed apparatus. This includes all of the components that are required for its operation. This design allows for easy ease of access to any of the components in case maintenance or changes needed to be made to the apparatus. Overall, the final design allowed for modular build that used off the shelf components that makes modification or replication of the device as simple as possible.

IV. Conclusion

Overall, this apparatus will allow Danfoss to save a lot of money when doing R&D and testing because of the time saving this device allows for. This will allow Danfoss to streamline its process of testing thermal interface materials and allow them to best choose a TIM that will serve their needs. With the data acquisition in the device, it will also allow Danfoss to improve the accuracy of their models of their products.

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The Flow of Magnetic Particles in Viscous Fluids

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Abstract— the research, development and results presented in this paper describe a user-friendly apparatus exploiting electromagnetic forces to control the motion of a ferrofluid. The project uses a matrix of Electromagnets and a Graphical User Interface (GUI) scheme which prompts a user to select specific sections of this matrix to enable and disable specific electromagnets. The design itself employs a system of voltage and current controlled relays in order to bridge the gap between hardware and software via an Arduino Mega 2560 microcontroller.

I. INTRODUCTION

Modern treatments of cancer include operations that are both invasive and costly to patients. Surgical treatments are second only to chemotherapy, and leaves little to be desired as it is an ongoing, expensive procedure that doses patients with large sums of chemicals that seek out and destroy everything from hair cells to cancer cells. The idea was to mitigate these treatment options in favor of one that was much easier to implement. This entails the research, design and implementation of the prototype built by our team.

II. METHODS AND MATERIALS

A schematic of the relay board is displayed in Figure 1. This design utilizes a series of voltage and current relays that process and manipulate incoming electrical signals by toggling switches within the relays in order to allow for the passage of electrical current when closed. Excited by current, electromagnets generate a magnetic field exerting a guiding force on the magnetic nanoparticles.

This design is intended to conform to the user via a flexible Thermoplastic Elastomer Filament (TPE). These cylindrical electromagnets were chosen due to their field distribution, ease of use in designing a comfortable and viable device for patients and the size of the electromagnets themselves. With a height of 1.2” and a diameter of 0.8” they are versatile in their ability to mount on various devices. Pictured in Fig., 2, this filament allows any interconnecting wiring to be routed without compromising the proximity to the users target area of treatment.

This filament also has a heat resistance that enables it to absorb excess energy generated by the internal resistance of the electromagnets while maintaining its desired size and shape. This protects the user first and foremost. Had we used a rigid design, the electromagnets would need to be remounted onto a different surface for every different application costing even more time and money, making this form of treatment highly inefficient. The novelty in our design is attributed, partially, to the aspect of conformability to the user.

III. SOFTWARE, INTERFACING AND POWER SOURCING

In the design and testing phase of the prototype we encountered relentless struggles in being able to easily control the matrix of electromagnets both physically and electronically. The GUI was designed and implemented using the arduino IDE and allows a fully hands off approach in the implementation of the prototype. The central idea is that multiple electromagnets would need to be triggered in specific locations at specific instances of time and manually connecting a variable power supply to multiple electromagnets created a serious issue in the rapid
deployment of, and real time control in, the motion of a ferrofluid. Once the relay control board was designed and built the only problem remaining was that of interfacing with peripherals in order to toggle the magnetic fields for absolute control of the ferrofluid to and at a desired region of the patient’s body. Electrical power is supplied by an Ever Glow 120 Volt AC (VAC) Power Adapter. This power adapter converts the AC input into a 7V DC output sufficient enough to drive the electromagnets in order to generate a magnetic force capable of producing the desired effects on the stream of ferrofluid. This was crucial as too small of a voltage would generate an insufficient magnetic force and would not grant the full control needed for successful treatment. Too large of a voltage creates the opposite problem, too strong of a magnetic force makes it nearly impossible to successfully navigate the ferrofluid but is absolutely essential in more direct applications such as thermal ablation where a stream of ferrofluid is rapidly oscillated back and forth over a specific site in order to collapse unwanted growths attached to musculature and organs that may be otherwise damaged in an operation where they would be physically excised. These obstacles were overcome by using a step down AC to DC buck converter in addition to the voltage and current relays.

IV. DESIGN

The design for this project consists of 30 electromagnets attached to a 3D printed TPE Filament with a bag of oil placed on top. The bag of oil will have a droplet of magnetic fluid which will be used to demonstrate the flow of the magnetic particles in a viscous fluid. The electromagnets are attached to a 12 V power supply and some are selectively chosen to turn on and off to have the magnetic fluid flow to a specific spot to illustrate magnetic drug delivery. This is represented in the Figure 3.

This project will explore the limitations of guidance in current procedures where magnet drug delivery/hyperthermia is achieved by either passive and/or active targeting. Through this design, the user will be able to guide the magnetic particles to whatever complex direction of choosing. This will be accomplished via a code that incorporates Arduino Mega and code to turn on and off specific electromagnets. For this design purpose the 30 electromagnets will be arranged in a 5 by 6 fashion as seen in Figure 4, bolted to a 3D printed thermoplastic elastomer filament mesh.

![Fig. 4, Electromagnetic Placement Grid with Oil Bag containing Magnetic Fluid – 2D](image)

![Fig. 5, Electromagnetic Placement Grid with Oil Bag containing Magnetic Fluid – 3D](image)

V. RESULTS AND DISCUSSION

The performance of the prototype designed is as desired in its ability to systematically and algorithmically manipulate the flow of a ferrofluid bound with medicine to treat tumors. Testing of the prototype was successful in demonstrating the goal of our project and its extensive capabilities in customizability, user simplicity and effectiveness in its assigned tasks. Functionality of the prototype was recorded and displays the intended modes of operation. Future entails a device that is a flexible and safe to use on human beings for purpose of magnetic drug delivery as represented in Figure 5.

VI. CONCLUSION

The prototype design was modified in order to accommodate the impossibility of face to face interaction. This was an unfortunate setback as it forced us to alter our design using components that provide the visual representation of our intended functionality without the use of those we set out to use including the matrix of electromagnets and the TPE filament. In future iterations of this project, this can be achieved given the research and design considerations that our team has conducted on electromagnets, magnetic nanoparticles, the biological systems involved in thermal ablation and the treatment of parasitic tumors as well as the control system functionality of the prototype.

VII. REFERENCES

Humidified Shaking Incubator

Team 50

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Abstract—The following paper covers the development and construction of a Humidified Shaking Incubator. To be specific, the functionality of this device is to provide physical agitation to chemicals in test tubes in a temperature and humidity-controlled environment. Controlling the variables of temperature, humidity, and speed of agitation allow the user to more precisely replicate the real-world application of their research. This in turn increases the quality of their research improving the development of everything from medicine to fertilizer. Although there are incubators on the market that provide humidity-controlled incubation, they are prohibitively expensive to many entities. The goal of this project was to create a low cost, market competitive, solution. Much of the physical and most of the electrical/coding work has been completed, however because of the pandemic completion was impossible. Although proof of concept testing was successful.

I. INTRODUCTION

When preforming research in the biomedical field it is critical that as many variables as possible within the environment are controlled. In the past, devices for achieving a controllable orbital motion, humidity and heating have been built, however the cost of said devices is high and they may not provide the level of control needed by a researcher. This creates a need in the world for a cost effective, easy to control incubator. This project of creating a shaking incubator is a second-generation project, this allows for the reuse of parts from the old prototype which will bring the cost of the new design down significantly.

The purpose of this project was to create a humidified incubator with a shaking platform for preforming experiments. The incubator must maintain 100% humidity and be able to maintain constant temperature ranging from room temperature to 100 degrees centigrade. The motivation behind the development of the project came from the fact that Northern Illinois University’s professors lack such a machine due to budget constraints. In fact, when looking at competitive devices and patents, very few offer the ability to control humidity. Our new design will also have a modern graphical user-interface (GUI) to control all operations, something not seen on other market solutions.

With the exception of the fiberglass insulation our incubator is made of entirely recyclable materials. This is important as large amounts of otherwise reusable materials ends up landfills every year.

II. COMPONENTS

The following is a brief overview of each of the components of the incubator.

A. Housing

The housing itself is made up of two compartments: the incubation chamber and the electronics/control compartment. The incubation chamber is 18” long by 18” wide by 14” high. It includes a door for unloading and loading, an input for the motor shaft, and intakes for heat and humidity. There are two sub housings for the chamber itself: an aluminum interior and a stainless-steel exterior. In between these two layers is a layer of fiberglass insulation. This layer of insulation will prevent the outside housing from becoming hot enough to burn the user or people who may touch it. The insulation also improves the energy efficiency of the unit. Holding together the chamber sides are rivets and bolts. The chamber is mounted on top of the electronics compartment. Four stubs protrude from bottom of the electronics compartment to support the incubator. All electronic components are mounted to the bottom of the compartment to avoid excess heat from the incubation chamber. The compartment is made of 1/8in stainless steel and has inlets for power. The front of the compartment is also slanted and holds the LCD displays and the power switch. A water tank is connected to the side to feed the humidifier.

B. Porthole

A major addition we made to our generation of the incubator was a porthole for visual monitoring of incubation. The porthole is made from two 1/4” panes of tempered glass separated by a purpose made Viton spacer. A one-way valve was inserted into the spacer to so that air can be removed creating a vacuum insulation effect. A porthole cover was also designed but not built, it is needed as some chemical reaction are photosensitive. Lastly, high temperature resistant lights were acquired and were planned to be installed in the chamber to improve viewing.

C. Electrical Components

The electrical system consists of temperature/humidity sensors, fans, high temperature lights, an ultrasonic humidifier, and a motor all connected to a relay bank. The relay bank is connected through an AC/DC converter to wall power and voltage is stepped down at each relay per the voltage requirements of the components. A pair of heating elements is connected directly to wall power. Controlling all of these components is an Arduino. Connected directly to the Arduino are a pair of LCD screens for taking user inputs and displaying internal conditions. The Arduino controls most of the components by turning on and off the relay that
they are attached to. A notable exception being the heating elements which are connected to the Arduino through a shield. The control method used for the design is PID. In basic terms what happens is that when the temperature and humidity are set by the user, the Arduino turns on the heating elements and humidifier. Once conditions hit the top of a narrow range around the input, the Arduino shuts off the components. As conditions fall the bottom of the range the components are turned back on, see figure 3.

III. RESULTS AND CONCLUSION
Before spring break, we were ahead of schedule, however because of current events we were not able to complete the project. We were however able to conduct proof of concept testing. The code was used to control the different electrical components which responded as desired in a cardboard box meant to simulate the incubation chamber.

After completing the virtual build, it is our belief that should the stay at home order be lifted, the physical reconstruction of the incubator could be completed in as little as a week. Basically, what needs to be done is to fashion a porthole cover, replace some rivets with bolts, install the internal lights, and bring everything together. Once everything is together, its basically fine tuning until it works as desired. Budget wise, we were well below budget spending about a third.

IV. FIGURES

Figure 1. SolidWorks Model.

Figure 2. Wiring Diagram

Figure 3. Control Ranges.

ACKNOWLEDGMENT
Our Team would like to express our sincerest appreciation for the invaluable guidance and mentorship we have received over the past year from Dr. Sahar Vahabzadeh and Dr. Hasan Ferdowsi. The lessons we have learned from this experience will last a lifetime. We would also like to thank our TA Sandhya Chapagain for her dedication and patience. Finally, we would like to thank Mr. Edward Miguel for assisting in the development of our electronics layout.

REFERENCES
Abstract—The Integrated Output Spectroscopy (ICOS) instrument is designed to detect miniscule chemical leaks in natural gas plants. The ICOS instrument can be deployed on unmanned robotic systems allowing it to accurately record chemical leaks without risking human exposure. The vibrational stresses experienced by the instrument must be minimized to protect its sensitive components. To solve this problem a vibrational testing framework was created to determine the ideal housing solution. By collecting the necessary vibrational data the parameters in which the deployed ICOS instrument can operate reliably will be determined. From the results, a specification for dampeners will be created to minimize vibration effect. The document will also serve as a guideline for further vibrational analysis.

I. INTRODUCTION

Natural gas production in the U.S. remains strong and in increasing demand as it is used in industries and homes across the country. This increase in demand has resulted in the expansion of natural gas production centers. As these facilities expand so too does the need for worker safety and environmental protection.

This leads to the development of a safe method to seek chemical leaks in a natural gas plant. A more optimal solution proposes placing an ultra-sensitive Integrated Cavity Output Spectroscopy (ICOS) system onto a remotely-operated ground rover that is able to roam the plant area. The ICOS system is able to detect dangerous gas leaks with a high degree of accuracy using a combination of highly sensitive components. The sensitive nature and placement of these components leaves the system vulnerable to mechanical vibrations from the rover’s motor and its operation over the plant’s terrain, resulting in skewed results.

The ICOS system is able to identify trace gases using narrow band lasers from a tunable laser source directed into a gas-containing cavity. This laser would then hit concave cavity mirrors, shown in Figure 1, causing it to bounce back and forth which increases its sensitivity and the distance the laser travels to ~3km. The laser passes through the collimating optics and into the detector which is able to measure changes in its intensity after the gas absorbs the laser’s wavelength [2][4]. The highly sensitive nature of these measurements requires testing its accuracy when mounted to a movable platform. It was noted that in prior tests the system did experience visible shaking, resulting in skewed results and not addressing this issue could lead to equipment failure.

Figure 1. ICOS laser reflects off concave mirrors.

This document details the steps taken to address this issue by identifying sources causing scanning inaccuracies using computer models of the laser cavity and the test rover using ANSYS software. ANSYS will be used to place the digital models under real world stresses and show vulnerable points in the physical models. These results will be used to strengthen those weak points in the form of dampening solutions. A data logger will be used to record vibrational data while attached to the test rover with the ICOS instrument mounted. When driving through the rough terrain the parameters at plays that cause the laser source to move and no longer hit the detector when analyzing our data will be determined.

II. ANSYS MODELING

In order to provide accurate simulations the ANSYS modeling software will be utilized. Solid works models are used to accurately recreate the ICOS instrument along with its proposed housing design for simulations. Through ANSYS modal mesh analysis in conjunction with random vibrational analysis the results as shown in Figure 2 and 3, to obtain power spectral density curves at resonant frequencies are produced. These harmonics allow us to gain a greater understanding of displacement forces acting upon the instrument.

Figure 2. Meshed housing model in modal analysis.
III. FIELD TESTING

The rover that was used for field testing was a Traxxas TRX-4 Scale and Trail Crawler. It’s body kit was removed, leaving the vehicle’s frame exposed, and replaced with a flat 2’x4’ platform. A replica of the system was set on the platform and made to account for the weight and dimensions of the actual system. This includes the ICOS system, a diaphragm pump, and all relevant electronics. The ICOS replica was constructed by drilling a laser diode into a sheet metal box pointed at a detector that was secured on the opposite end. The detector consists of a photo resistor connected to a set of diodes indicating a range of intensity the photo resistor is being hit with. The ICOS replica and the dummy weight were secured onto the platform using screws without dampening material as a baseline was needed to be established. An accelerometer, used to measure and record vibrations, was secured onto the vehicle’s frame.

The rover would traverse a wide variety of terrain while patrolling a gas plant and avoid obstacles in front of it. The system may experience gravel, rocky, smooth and paved surfaces and possible crashes into obstacles due to user operation. The readings should be accurate while operating under these conditions; the laser should still be able to hit the necessary targets to produce accurate and reliable data. For the purposes of this test, a successful run would result in minimal to no loss of intensity shown by the light indicator.

IV. RESULTS AND DISCUSSION

A. ANSYS Results

Through our ANSYS simulations we were able to develop an understanding of the harmonics of the majority of components within the ICOS instrument. Our analysis was able to identify several key weaknesses such as the pump component, laser cavity and housing. As seen in Figure 3 the housing suffers from intense displacement deformation at the 700 Hz resonant frequency. We were able to determine through shock simulation the failure of pump integrity. After 7100 Hz the pump component experienced large deformation leading to collisions with the aluminum base plate.

B. Field Testing

The rover including the mounted dummy load was put through multiple runs, which include three different terrains; uniform pavement, gravel, and stairs. A camera was mounted behind the instrument allowing the LED activity to be recorded. After these runs, the footage showed that the LED stayed on and constant, indicating that the laser contact to the photo resistor was also constant. The data logger in conjunction with more accurate sensors would more accurately showcase results in further testing.

Though our test did not show possible failure, it did present important take-away. Vibration data was collected on the three different terrains, uniform pavement, gravel, and stairs, as shown in Figures 4, 5, and 6 using the accelerometer. The various vibrational stresses for each terrain type can be determined.

This data can be used in further tests to improve analysis of vibration and shock effects on the instrument. Using a shaker table and laser vibrometer, Figure 7, would help create a more controlled test environment in future tests for the original ICOS sensor to undergo.

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REFERENCES

Voice Controlled Injector for Medical Procedures

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Abstract—During the endoscopic procedures, surgeons need to focus and work with both hands. It becomes difficult for the surgeon to control extra equipment with one hand or rely on an assistant on what exactly they need to be injected. This device helps the surgeon with better control and creates a low-cost device. The surgeon can control the device with voice commands or manually via the physical buttons if need be. This device cuts out the middleman and drastically reduces the chance of mistakes by human error. As a result, endoscopic procedures become safer for patients and more convenient for surgeons. This device will be portable by utilizing a battery as a power supply. The control system of the syringe pump will use a raspberry pi to receive input, perform calculations, and send signals to a motor controller. The motor controller, powered separately from the raspberry pi, will control a stepper-motor which has a 3D printed attachment that will push or pull on the syringe to control the flow.

I. INTRODUCTION

During endoscopic procedures, it can be difficult for doctors to operate an endoscope while also communicating with a technician who is injecting a dye at the site via syringe. Excess volumes of this dye can lead to pancreatitis within the patient [1]. This device will use voice commands to inject the exact amount of fluid and speed requested by the surgeon. The device will also work with standard syringes readily available in all hospitals. Having a device that will inject exactly how the surgeon wants will help streamline this important procedure.

II. MATERIALS AND METHODS

The program starts with the variables set to 0 and the voice software listening for the command word. At this point, the speed and volume variables are available to be altered by the encoders or voice commands and the motor can be moved via the onboard buttons continuously. Once the “Inject” command is given or the inject button is pressed, the variables are no longer able to be changed and the motor will start to move the pump accordingly. The injection can always be stopped via command or pressing the “inject” button again. The force required to push the syringe simplified with the pulse. The user gives the command of volume flow rate and will be converted into a pulse and push the syringe under command.
The voice control system was created by using a multitude of programming and technologies. All voice control related software and processing was located locally on the raspberry pi, allowing the device to work completely standalone and offline. The overall process of the voice control system can be summarized as a few steps. The user first speaks a predetermined wake-word which will trigger the device to listen for commands and make a sound to alert the user it is ready. The user speaks a command and the sound is analyzed by the speech to text program, which sends the command in text form to determine what the intent of the command is. When the intent is identified, it is sent to an intent handler, which executes pre-defined code based on the specified intent.

Voice recognition centered around the software Rhasspy, which is a completely open source voice assistant toolkit. Rhasspy acts like a hub for a variety of voice related tech to work with one another. The wake-word technology used was Porcupine with the default word, “Porcupine,” being used. The speech to text program used is called PocketSphinx, which contains its own dictionary and needed no extra training. PocketSphinx would send the translated phrase back to Rhasspy, which would then determine the intent. Intents were labeled by programming phrases with optional or alternative words to allow for leniency within phrases. This programming also labeled a number given as a variable. Rhasspy sends the intent and variable to the programming software Node-Red through websockets and local host connections. Node-Red would run certain flows of code based on the received intent and variable number.

III. RESULTS AND DISCUSSION

The stepper motor required 20 volts to operate. The performance was different than expected due to some technical issues. Finding the correct settings to operate the stepper motor was difficult and it made loud noises when running the command code. Too much current ended up being supplied to the motor and a new one was ordered to replace the melted one. Throughout testing, the motor had no response to the commands, even when no error was given upon execution. A pressure sensor was to be used with a feedback loop to provide a constant flow, changing pressure as the force required to inject at the desired speed changed. The rotary encoders were able to adjust the variables continuously along with the voice activation software by having them both write to a single text file. These encoders are important as they provide an alternate way for a doctor to adjust the settings and bypass spoken commands completely. It was decided that an LCD screen was needed as an interface to inform the user of the current settings and the “ready state” of the device. It was decided that the information on screen should be readable at a glance.

![Figure 3. Voice activation code logic](image)

IV. CONCLUSION

The voice-controlled injector takes some of the workload from the doctor. Through local hosting and processing, the unit is portable and completely offline. With high accuracy and stability, the doctor can focus on the surgery without worry about excess dye injections that cause pancreatitis.

Acknowledgement

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References

Semi-Automated Wheel Lift Mechanism

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Abstract—Cars are everywhere and are the primary source of transportation for most of the population. One of the responsibilities of owning a car is having to do maintenance such as tire changes. Over half of injuries in a car shop are due to tire changes. The Wheelyft is a semi-automated lift mechanism that can aid in installing wheel and tire assemblies. With the use of ultrasonic sensors and a remote-controlled motorized lift, an Arduino is used to store the height value so that it can be recalled after the user is ready to re-install the wheel on the car. Also, with manually adjustable rollers, the lift can accommodate a wide range of wheel and tire sizes. The Wheelyft can be used by anyone in a shop or at home by DIYers that require an easy, stress-free solution to mounting wheels on their cars.

I. INTRODUCTION
Many car repair shops, and tire change locations require technicians to remove and install wheels on cars for eight hours at a time. This device would relieve the stress of such strenuous activity. Generally, the only ways a wheel can be placed onto a hub is either lifting the wheel up above your head or shoulder height (when the vehicle is on a lift), or sitting on the ground and trying to lift the rim up with very little leverage. Instead, the user would be able to roll the wheel onto the dolly and use a mechanism to lift the wheel up or down. The inspiration for this project comes from the team’s general interest in car repairs and desire to alleviate frustration with locating the stud holes on the hub. The purpose of this project is to create a functional prototype that can be tested and evaluated as a product for eventual production and sales to the public. Its value would be appreciated by all users as a means of making tire changing/transport an easier task.

II. MATERIALS AND METHODS
The primary material used in this design is low carbon steel. The main lifting mechanism is welded and powder-coated to prevent corrosion. It is rated to support 180 lbs. The top support plate is 11 Gauge (0.120” thick) A36 steel. After finite element analysis was performed on this plate, it was concluded that it can support 1000 lbs easily. This value was chosen to estimate the load on the plate if a large SUV were to fall onto the roller supports.

While the lift is not able to support a hydraulic jack failure, the plate itself would be able to withstand such a drastic occurrence. The rollers are galvanized steel. The roller supports are custom bent stainless steel brackets. Support blocks beneath the roller supports are constructed of Delrin plastic to save on weight and cost; they are still able to be drilled and tapped. The threaded rods and coupler are constructed of low carbon steel. The guide rods that run perpendicular to the rollers are constructed of 1566 Carbon steel. The support L brackets for the guide rods are constructed of aluminum. These brackets save weight and have great machinability, while still retaining strength to support the sliding roller mechanism. The crank handle is constructed of plastic with a pressed steel collar that can be captured with two nuts on the threaded rod. Finally all hardware is Grade 5 Steel.

Figure 1: Final Design
Figure 2: ANSYS Analysis
III. RESULTS AND DISCUSSION

The final product that was designed allows for the use of a remote control to move the lift up and down and store the height at which the wheel is with the use of ultrasonic sensors. It has a height range of 19.05 cm (7.5 in) to 73.025 cm (28.75 in) and, for proof of concept, can support up to 180 lbs. The upper assembly of the device can accommodate a combined wheel and tire diameter between 55.88 cm (22 in) and 93.98 cm (37 in). The total cost to make this device was $601.15. Compared to other devices that accomplish similar tasks, this costs less, mainly because of the materials used but one of the main trade offs is that

IV. LOGIC

The control system controls the linear actuator in order to raise and lower the lift. There are a few options with this lift; raise/lower autonomously, raise/lower with no sensor input (manual), and emergency shutoff. The programming was implemented into an Arduino Mega 2560 Rev3 due to its ease of use and cost.

The relays’ attached to the Arduino are also attached to the up and down buttons on the remote that came with the lift purchased instead of having to go into the actuator (essentially reprogramming the remote instead of the actuator). Also attached to the Arduino are two ultrasonic sensors which are used to measure the distance from the lift to the wheel. Once the sensors are within a certain range, in our case 5 cm, the signal to the remote is turned off which turns off the actuator until another input is received from the user. Once the signal is cut the time it took to get to the tire is stored as “elapsed time” (button 1). This time is then used to raise the wheel back to the height at which the wheel was at originally before being taken off the car (button 3). The elapsed time is also used to lower the lift back to the bottom with button 2. If working on another wheel, button 7 can be used to reset the values stored and start again. Buttons 4 and 5 are used to raise and lower the lift without any sensor input which means the lift will go up and down until the user decides to shut off the actuator with button 6.

V. CONCLUSIONS

The wheel lift and orientation device should fulfill the needs of many do-it-yourself and professional mechanics. It will save back breaking attempts to replace a tire and wheel by allowing the user to have the device hold steady the wheel for eventual placement onto the lugs in the proper radial orientation to successfully install the lug nuts. Getting the first nut started is the most challenging task, after that, the rest of them fall into place more easily. This phase is usually what frustrates many mechanics if they don’t have the luxury of a hydraulic car lift. With a well-planned approach to durability and economics, this device should make it affordable for most people

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REFERENCES
2 Degree of Freedom Labotory Helicopter System

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Abstract—The 2-degree-of-freedom (2-DOF) helicopter system is a lab aid used to study control systems as well as aerodynamic properties. The system allows for rotation in the pitch and yaw directions. A series of measurement encoders will precisely measure these pitch and yaw angles and will be able to communicate the output data to MATLAB and Simulink. The 2-DOF system will be an economic alternative to testing full scale systems. Furthermore, the small-scale project will be safer than testing the control systems on such vehicles. This system will have an economic advantage when compared to similar products on the market.

I. INTRODUCTION

2-Degree of Freedom (DOF) helicopters are used to run experiments and aid in presenting and educating on control systems related to helicopters. In this situation, the helicopter gathers data as it rotates, in the yaw and pitch directions, around certain points. This data is then used to calculate the helicopters overall yaw and pitch angles. Finding the pitch and the yaw angles can provide understanding of aerospace concepts, such as drag and thrust, as well as different control systems. The 2-DOF helicopter can be used in simple undergraduate level experiments to industry research. This helicopter system will send information directly to a computer program where the user can then interact and manipulate the control systems of the helicopter.

II. MECHANICAL DESIGN

The 2 degree of freedom (2 DOF) system functions by having two distinct mechanical sub-systems, each with its own set of encoders. One sub-system is the pitch component which is responsible for the angle of the horizontal shaft while in use. Meanwhile the yaw encoder records the rotation of the vertical shaft which supports the helicopter system. The motion generated is then converted via encoders and captured in MATLAB/Simulink.

A. Pitch component

![Figure 1. Helicopter full assembly.](image1)

Figure 1. Helicopter full assembly.

The pitch component consists of two identical rotor assemblies on either side of a PVC pipe each orthogonal from each other’s orientation (see Fig 1). From top to bottom on the adapter piece, that acts as the motor shaft (see Fig. 2), the assembly begins with a rotor cap to secure the rotor (A). Next is the rotor (B) followed by the rotary encoder and the necessary mounting bracket for said encoder (C). Finally, the motor is the end piece (D) and is fitted in the rotor guard (Fig. 2) which allows this assembly to be mounted at the end of a PVC pipe. In the middle of said pipe a dowel rod sits inside orthogonally to the PVC thus allowing it to be mounted to the acrylic yoke. At the end of the dowel an encoder is mounted to detect the angle at which the system moves. The acrylic yoke attaches to the bottom bracket and moves as a single piece in the yaw direction.

![Figure 2. Rotor assembly. Cap(A). Rotor (B). Encoder(C). Motor (D).](image2)
B. Yaw component

The yaw component of the 2-DOF helicopter allows for smooth 360-degree motion in the yaw direction. As the apparatus spins in the yaw direction, a belt pulley system turns the encoder shaft that is outfitted with a printed adapter piece to catch the timing belt. Figure 3 shows a section view of the belt pulley system. As the bracket bottom (E) turns, the yaw angle is recorded. In order to achieve this data acquisition, many components are required. The vertical shaft (F) is grounded to the base with four self-tappers. Two metal snap rings (I) are housed around the vertical shaft and inside the bottom bracket. A needle bearing (G) is then press fit onto the vertical shaft, which will allow for the yaw rotation. A slip ring (H) is screwed to the top of the vertical shaft, which allows wires to stay untangled as the components rotate. This slip ring fits into an opening in the bracket bottom which also fits over the needle bearing. Four, 8 mm set screws, threaded through heat sets in the bottom bracket, grip the needle bearing so the entire upper apparatus will rotate.

III. ELECTRICAL DESIGN

A. Electrical Components

The Two Degree of Freedom Laboratory Helicopter System has many different electrical components that are necessary for the project’s overall function. Primarily, the system is powered by a 12-volt AC to DC adapter. This adapter allows for the system to be plugged into normal wall outlets; thus, the system can be operational in any normal classroom. This power supply is attached directly to the motor driver of the system. The motor driver used for the system is a dual motor driver that could simultaneously drive both the pitch and yaw motors. The dual motor driver can operate with up to 28 volts giving the project enough voltage to operate. The motors used have an RPM of 3100 which is necessary for the system to take lift. The motor driver itself gets commands from a Raspberry Pi 3 Model B+ microcontroller. The microcontroller operates on low voltages received by user through a computer interface. The microcontroller also receives the data from the encoders in the system. Our system has four encoders total (Fig. 4). Two of the encoders are shaftless rotary encoders that are attached to the motors themselves. These encoders are used to track the speed that the motors are operating at. The other two encoders are incremental encoders and are used to measure the pitch and yaw angles. As the system turns the encoders send data to the Raspberry Pi. One unique electrical component to the project is the slipring based in the vertical shaft of the system. The slipring allows the system to rotate freely without the inner wiring getting tangled.

B. Matlab and Simulink Interface

The user interface designated for the project is a MATLAB and Simulink interface. Simulink is a tool in MATLAB that many individuals use to develop control systems. A control system can easily be developed using block diagrams inside of Simulink. However, our system needed to be able to communicate to MATLAB. In order to do this, software was downloaded onto the Raspberry Pi’s SD card to allow communication from the Raspberry Pi to the Simulink interface. Thus, now students can directly control the system directly through a PID controller developed on Simulink.

IV. CONCLUSION

The Two Degree of Freedom Laboratory Helicopter System is effectively able to send and receive data to MATLAB’s Simulink tool. The system’s final design was developed to achieve this goal. Students and researchers will now be able to use our system as a tool to better understand control systems and aerodynamics. Our system comes at a fraction of the cost as compared to other existing products on the market. Our system can also be easily maintained since most of the parts can be 3D printed or can be acquired relatively cheaply. Overall, the Two Degree of Freedom Laboratory Helicopter System can benefit those who want to better understand control systems and aerodynamics.
Automating Anti-Vibration Glove Testing following ISO 10819

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Abstract—The goal of this project is to create a biodynamic mechanical hand capable of producing and maintaining at least 40 Newtons of grip force inside a variety of anti-vibrational gloves. While gripping a 2-inch rod mounted on a dynamic shaker. The development of biodynamic artificial hand is designed to Automate the ISO 10819 testing standard process allowing for continuous testing and data collection creating ideal assessments of anti-vibrational gloves. The device will also eliminate the need for human testing, which is currently the method being used in industry at the moment. The hand is to be mounted and operated by a FANUC LR MATE 200ic robot with the capability to maneuver the hand into the desired position and initiate the grip force onto the rod. The full automation of the ISO 10819 will expand the amount of data being collected while allowing for trends within the material type to be identified. (Abstract)

Keywords-component; formatting; style; styling; insert (keywords)

I. INTRODUCTION

ISO 10819 is the gold standard certification, used as a procedural guide to test anti-vibration gloves, to deem them acceptable for public use. It ensures that the gloves design can reduce the vibration transmitted from powered handheld tools to the user’s hand. Reducing the damage being done over long periods of time in order to decrease the possibility of developing Hand-Arm Vibration Syndrome (HAVS). This syndrome causes sensory dysfunction, vasospastic problems, Secondary Raynaud's phenomenon of the hand, and Musculoskeletal problems [5]. Those most affected work within construction, maintenance, and lawn care fields.

Symptom's may not arise until 10+ years of repeated vibration exposure depending on the individual’s hand structure [5,4,7]. The current testing procedure used to certify anti-vibration gloves involves an individual physically wearing a glove designed to nullify the vibration while gripping a 5.08 mm rod attached to a electrodynamic shaker which exerts low to high frequencies onto a test subject using the rod as a conduit. Humans are currently being used as test subjects to measure the efficiency of various gloves designed to dampen the vibration transmitted from the tool to the hand of the user.

Considering that the test subjects can have future complications due to prolonged exposure to high or low vibration frequencies, this method of testing the gloves can be classified as un-ethical and dangerous for those who volunteer or get a small compensation to become a test subject. The project’s main purpose is to develop an artificial hand to be used in an ISO 10819 testing procedure. This artificial hand replaces human testing currently being used. The technology currently available makes it possible to create a substitute hand. Designed to analyze the efficiency of anti-vibration gloves, while making the testing procedure more efficient. With an adequate design testing eliminates risk to the human subjects while producing a more standardized process for evaluating the functionality of various anti-vibrational gloves aimed at damping vibrations transmitted to the human hand. The design includes a minimum 40 newton grip force to ensure the gloves material and design are being fully assessed within the testing processes. Introducing a high fatigue limit ensures the structural integrity of the device under high or low vibration frequency caused by continuous testing. Hand size must be comparable to the average human hand to ensure all glove designs fit. The hand will be made in a specific way for it to be mounted into a FANUC LR MATE 200ic robot which will also maneuver and control the internal mechanism used to exert a gripping force of 40 newtons.

II. DESIGNS

The structural integrity of any device with multiple small mechanical components can be comprised by excessive vibration exposure, this vibration leads to malfunctions in hand movement and the possible deformation of the mechanical hand. Therefore, the mechanical design and material used to construct this mechanical hand are chosen carefully to ensure the structure integrity of the hand is maintained.

Within a FANUC LR MATE 200ic manual the J6 axis is referred to as the end effector this interface will be used to control the hands’ movement and grip force as it rotates, the robotic arms programming makes it possible with its simple panel outline. The manual also introduced a motor rotation limit of 720 degrees this was taken into consideration within the design phase.
The coupler designed by the team is termed “The Puck” it is responsible for converting rotational motion to a linear motion, connecting the artificial hand to the J6 axis, and maintaining the grip force throughout the process. The second component designed by the team is the palm to puck coupler. This coupler is round on one side while it is rectangular in shape on the other, it is meant to hold the palm on the rectangular side while latching on to the puck through the other side. This component is responsible for maneuvering the pathway of the braided cable from a linear path to a radial pathway in order to distribute the force vector on the puck, locking both the puck and palm in place, and translating the linear force used to maintain the artificial hand on the dynamic shaker. The palm designed by the team is made so the braided cable can travel through it, while housing a system to allow the hand to open again. The last components are the fingers which were made to be 12.5mm in order to represent human bones while allowing for flesh-like materials to be added in the future making the testing more realistic in nature.

III. MATERIAL AND METHODS

The material for this biodynamic artificial hand was chosen specifically for prototyping, and testing, meaning the material had to be easily machinable and durable for continuous testing. Using NIU’s makerspace 3D printer for the complex components, the Machine shop & E-Machine for the metallic components. Aluminum 6061 was used for the metallic components, and film resin was used for 3D components.

IV. RESULTS AND DISCUSSION

The biodynamic artificial hand was tested and analyzed using simulators, giving validity to the basic design model created. The resulting hand model allows for the application of a tissue like material, such that further testing and analysis may proceed.

Expansion of the pathways governing the transmission cable dimensions were expanded to allow the use of larger cables in the event of physical testing failures. Vibratory testing, in the theoretical sense, would be largely founded with no reasonable data derived from a computational simulation. Thus, it was applicable to use static analysis to drive the spring selections that dictate resistances that relate the developed motion of the hand assembly to the subjected vibration metrics used during testing. Each element of the hand assembly asserts realistic design concepts alongside a demand to narrow the sight of future project limitations.

V. CONCLUSION

Manufacturing a biodynamic artificial hand used in automating the testing safety procedure for anti-vibrational
gloves will reduce the number of human subjects exposed to the procedure. The device creates other benefits such as retaining a baseline variable to which each separate glove can be compared to. Meanwhile the hand can be altered in different ways to better mimic another person’s hand with known vibrational properties such that to keep the tests valid for ISO 101819. Anchor points to allow other types of materials to be added thus changing the vibrational response. More real-world experimentation can be done to adjust further how accurate the hand will be to a human’s hand holding the dynamic shaker. The mechanical hand needs to have a different vibrational response, material can be adjusted to different types of human hand sizes, densities, lengths. With this added material in mind the smaller frame built provided some challenges in simulations with stability during vibrational forces. Some of these challenges stem from the fact the simulations provide data on certain assumptions that will not be the same during real world testing. Analysis on the phalanges confirmed some of the original problems concerning the transmission cable that can be possibly solved on a later date. The device as it stands has the theoretical ability to grasp with 40N-100N force from the torque of a FANUC arm with no substantial concern of vibrational failure.

ACKNOWLEDGMENT

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REFERENCES


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Development of a Heart Rate Monitoring System
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Abstract – The Heart Rate Monitoring System Prototype is designed to address grade school students conducting Science, Technology, Engineering and Math (STEM) activities. Dr. Pi-Sui Hsu of Northern Illinois University’s College of Education is conducting a research project that monitors these students’ anxiety levels. This device was created with the optimal cost and functionality needed for this research. The design implements feedback by inputting data from a pulse sensor and processing the data through an Arduino Nano. A beats per minute (BPM) calculation is made and sent to an excel file for storage and later analysis.

I. INTRODUCTION

STEM related activities can be stressful for middle school students. Heart rate can be used to determine stress and anxiety levels. Smart wearable devices on the market today can be used to measure heart rate. However, they are extremely expensive and do not export the raw data needed. The goal of this project was to develop a heart rate monitoring system that is low cost and can measure the wearer’s heart rate. The beats per minute of the wearer is exported to a computer. The BPM is then rechecked every two minutes. This will provide a longer and more accurate collection of data. The anticipated result is for one to interpret the data in order to know when someone is feeling anxious and needs help.

The client, Dr. Hsu, is an associate professor in the Educational Technology department at Northern Illinois University. Dr. Hsu has conducted research in the area of science and engineering education for middle school students. Six to eight grade school students are given science and engineering activities to work on and their anxiety levels are then observed. The anxiety levels can be monitored using heart rate. Biodots (stickers that change colors depending on stress level) are currently used to observe anxiety levels. This method relies only on a person’s observation skills, which is not accurate or reliable enough to use in a research study. It would be far more accurate to use heart rate measurements to observe the students’ anxiety levels because data is sent to the computer and stored for a more accurate observation for a later time.

It is important for the client to be able to wirelessly monitor the data while it is being recorded so she can observe it and intervene to help the students whenever they feel anxious. The data also need to be stored so they are available for analysis in the future. There are similar devices currently on the market that could also do this, but they are too expensive and do not provide raw data that can be analyzed and recorded. It is also ideal for this device to be cheaper than current devices on the market.

There are a few similar products on the market, most of them being fitness bands. The E4 wristband by Empatica is a wristband that measures heart rate and temperature among other things related to fitness [1]. The wristband uses a photoplethysmography sensor to measure blood volume pulse, which can be used to derive the heart rate. Another similar product is the Apple Watch Series 4 or later. It also uses photoplethysmography, like the E4 wristband. The Apple Watch uses green LED lights and light sensitive photodiodes to detect blood flow in the wrist. When the LED lights flash hundreds of times per second, the number of heart beats is calculated, which is the heart rate [3]. These devices are simply too expensive and do not provide live raw data to be analyzed.

II. METHODS AND MATERIALS

A schematic diagram that shows all the components and how they are connected is shown in Figure 1. The design contains approximately 8 components: Arduino Nano board, pulse sensor, lithium ion battery, battery charger, HC-05 Bluetooth module, enclosure, power switch, and a wrist strap. These specific components were chosen to make the device as compact and efficient as possible.

Figure 1: Schematic
The pulse sensor connects directly to the Arduino Nano board. The lithium ion battery is plugged into a charger which then connects to the Arduino’s +3V and ground pins. A switch breaks up that wire connecting the battery charger to the voltage supply pin. This allows the power to the device to be turned on or off from the switch on the enclosure. An HC-05 Bluetooth module is used to connect the Arduino to a computer via Bluetooth. This allows the device to be worn wirelessly and thus limits the movement restrictions on the device. The connections needed between the Arduino and the HC-05 module are also shown in the schematic.

Once connected, all the components of the device are put into an enclosure. This is a 3D-printed enclosure which includes insets and holes for all the components to easily fit inside. Figure 2 shows what this enclosure looks like. The bottom of the enclosure sits on top of the wrist and is worn with a wrist strap.

Once the BPM is calculated, it is sent to an excel file along with information such as the date and time it was recorded. A sample depicting how the data is formatted into excel is shown in Figure 4. This BPM can then be used to calculate the stress level of the person wearing the device. Generally, the average heart rate is 60-100 BPM [2]. The higher your rate raises outside of its normal range, the more stress you are experiencing.

### III. RESULTS AND DISCUSSION

Figure 3 below represents the pulse waveform that is being inputted into the Arduino. The BPM is calculated by counting how many times the waveform passes through a set threshold in sixty seconds.

Once the BPM is calculated, it is sent to an excel file along with information such as the date and time it was recorded. A sample depicting how the data is formatted into excel is shown in Figure 4. This BPM can then be used to calculate the stress level of the person wearing the device. Generally, the average heart rate is 60-100 BPM [2]. The higher your rate raises outside of its normal range, the more stress you are experiencing.

### IV. CONCLUSION

A new low-cost heart rate monitoring system was developed to study anxiety levels for a research project. The device consists of a custom-made enclosure with a complete circuit to detect the pulse of the user. A data acquisition system, controlled by a microcontroller and software, was used to acquire the pulse signal and wirelessly transmit the data to the user’s computer simultaneously. This newly developed system will be used in the client’s research projects to study anxiety levels of grade school students soon.

### ACKNOWLEDGEMENT

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### REFERENCES


Drain Water Heat Recovery System

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Abstract—The Drain Water Heat Recovery System (DWHRS) is designed to raise the efficiency of a residential building’s water heating system. The device captures heat from drain water as it flows through a residential building’s drainpipe and into sewer. The system then applies that collected heat to the incoming fresh water before it enters the building’s water heating system. With the incoming water preheated to a higher temperature than when it first entered the building, the water heating system will use less energy to further raise the water’s temperature. The design of the DWHRS addresses the drawbacks of currently available heat recovery systems, and it is designed to be compatible with Chicagoland’s least energy efficient buildings; prewar multifamily buildings.

I. INTRODUCTION

Heated water that passes through a waste drain is energy waiting to be used. In today's climate, a lot of resources focus on being efficient or environmentally friendly. Whether it’s a car being fuel efficient, light bulbs being energy efficient, or even water bottles being biodegradable. Heating water is a resource that should be energy efficient also. The Drain Water Heat Recovery System (DWHRS) will increase water heating efficiency which decrease the energy needed to heat water. The Drain Water Heat Recovery System uses heated wastewater to pre-heat incoming cold water before it enters a building’s water heating system. If water enters a water heating system at a higher temperature than when it first entered the building, the water heating system would use less energy to heat the water. This would result in the water heating system having a lower energy output and a lower energy input requirement. Drain water heat recovery devices can add this efficiency to the water heating process. The targeted demographic of this project’s heat recovery system is pre-war multi-family housing units located in the city of Chicago.

A “pre-war” building is any building that was constructed before World War II. These old constructions were made to be sturdy, but they were not designed to be energy efficient. This has led to prewar buildings consuming much more energy than later builds, and this problem needs to be addressed. The Chicago metropolitan area has approximately 136,657 prewar multifamily housing buildings that equate to about 500,110 units. everyday day, a single unit in a multifamily building can produce from 10.8 to 39.41 MJ worth of heat in the form of drain water. The entirety of the Chicagoland area’s prewar multifamily housing lets about 5.4 to 19.71 MJ of heated water pass through their drainpipes. This amount of heat equates to as much as $859,545 down these buildings’ drains on an average day.

II. DESIGN FEATURES

A. Overview

All drain water heat recovery devices collect heat from hot drain water and reapply that heat to incoming fresh water. The main differences between available systems are installation location and the design of the heat recovery device itself. Many systems are installed in the place of a length of drainpipe, so they encounter drain water from all water-using appliances in a building. Others are designed to only encounter greywater, water from showers or sinks. All of them, however, need a building’s incoming water to be redirected through the device. Therein lies the main difference between existing products and the topic of this report: The Drain Water Heat Recovery System. Unlike existing heat recovery systems, the DWHRS attached at the drain stack(s) and extends to the incoming water service, so the service does not need to be rerouted. The remainder of this section includes descriptions of the DWHRS’ subsystems and explanations of them.

The Drain Water Heat Recovery System consists of a compact plate heat exchanger, a shell and tube heat exchanger of this group’s own design, and a heat transfer fluid (HTF) running through both. The heat transfer fluid collects heat from drain water in the Wastewater Heat Exchanger and applies that heat to the incoming water in the Plate Heat Exchanger. The selected plate heat exchanger has an estimated effectiveness of 97.98% and a pressure drop of less than 1 psi (Pa) on the freshwater side, so it works well with the DWHRS [1]. The selected heat transfer fluid is Dynalene HF-LO. It is a low-odor, nontoxic, and noncorrosive heat transfer fluid that was selected based on its performance inside the Wastewater Heat Exchanger and comparisons with other fluids [2].

The prototype DWHRS, depicted in Figure 1, simulates drain water with a pump and tank type configuration. Above the prototype sits a plastic storage bin with a bulkhead fitting installed on one of its faces. The bin is filled with water to start prototype operation. It is released by a valve that is attached to the top of the WWHE. The “drain” water flows through the device, gets forced through the PHE by a small water pump, and is heated by an electric tankless water heater. The hot water is then finally pumped back into the bin. Now that the water is hot, it will give off heat to the HTF as it makes another pass. Afterwards, the water is cooled down to room temperature by an ice filled bin and pushed towards the PHE by the pump once more.
B. Wastewater Heat Exchanger

The Wastewater Heat Exchanger (WWHE) shown in Figure 2 is a counterflow shell and tube heat exchanger that was designed over the course of this project.

The 3/8” Type K copper pipe on the inside is in the shape of a spiral and carries heat transfer fluid (HTF) upward through the WWHE. As the simulated drain water flows downward around and over the coiled pipe, the hot water transfers its heat through the wall of the pipe and to the heat transfer fluid. The HTF then carries that heat toward the plate heat exchanger for the next phase of the process. The Wastewater Heat Exchanger’s copper pipe is encased in a 4” PVC pipe to prevent heat loss to the surroundings.

The heat exchanger has been simulated in MATLAB using both steady-state and transient models. The NTU-effectiveness method of analysis was used to first design the WWHE. Steady state results of the full-scale device yielded an expected heat exchanger effectiveness of 68.0% at an average drain water temperature and flow rate in a profiled building of 65 occupants. The prototype sized WWHE performed at 62.08% effectiveness under the same conditions. It should be noted that the difference between the prototype and full size WWHE is a height difference of 1 foot, so transfer area and time is increased with height.

Further analysis with transient methods yielded an average first-pass effectiveness of about 55.7% for the WWHE and 54.5% for the whole system. The transient calculations vary greatly with the drain water related inputs. Specifically, the system is dependent on the drain water’s temperature, flow rate, and event length. The data gathered using this method often considers only a single hot water use (shower, sink, etc.) or an average of multiple flow rates and temperatures based on usage trends. Table I depicts how the WWHE and DWHRS compare to existing wastewater heat recovery products.

<table>
<thead>
<tr>
<th>Heat Recovery Product</th>
<th>Effectiveness Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>RenewABILITY Powerpipe R2-72</td>
<td>53.8%</td>
</tr>
<tr>
<td>Showersave Recoh-vert</td>
<td>62.0%</td>
</tr>
<tr>
<td>Heatsnagger VXPipe</td>
<td>57.6%</td>
</tr>
<tr>
<td>WWHE (Steady-State and Transient Analysis)</td>
<td>68.0% &amp; 55.7%</td>
</tr>
<tr>
<td>DWHRS (Transient Analysis)</td>
<td>54.5%</td>
</tr>
</tbody>
</table>

As mentioned earlier, a single unit of a multifamily building loses about 12.13 to 39.41 MJ of heat go down the drain on an average day. Only about 6.56 MJ of heat is recoverable, but 3.575 MJ of that can be recycled with the DWHRS at a rating of 54.5% effectiveness. This equates to a daily savings of 15.6 cents per housing unit. This means that the effect of a DWHRS in all of Chicagoland’s prewar multifamily housing would be $77,971.42 of savings on an average day.

III. CONCLUSIONS

Pre-war buildings are the focus of this design project due to their poor performing water heating systems. The energy consumption is extremely high which leads to high cost in power for the water heater. The Drain Water Heat Recovery System can recover an average of 54.5% of available heat and has the potential to save the Chicagoland’s prewar multifamily housing 28.5 million dollars on energy each year. Extensive work was put into this design. However, due to the COVID-19 outbreak, an actual prototype was not able to be assembled. Instead, computer aided design software was used to complete this project.

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REFERENCES

Abstract – The goal of the Recyclops is to convert recyclable plastics and rejected 3D printed parts into new filament spools. With a user-friendly and compact design, the appeal of this device focuses on hobbyists and small businesses. To accomplish this, the material undergoes multiple stages of shredding, melting, extruding, and coiling. A user interface is implemented to display, and control rotation speeds and heating temperatures based on the type of plastic for optimal quality of the final product.

I. Introduction
The rise and improvements of additive manufacturing in both the manufacturing industry and low-volume production hobby communities opens a new path for ideas to emerge. New products and techniques can assist the additive manufacturing processes usefulness and practicality while simultaneously driving down its undesired economic expenses. This new era also presents the urgency for green alternatives through reducing, reusing, and recycling. An attempt to apply this generation’s green initiative in 3D printing is being made by few products currently on the market. However, they are unable to apply all necessary steps for filament conversion in a single, user-friendly device. The Recyclops aims to seamlessly accomplish the conversion from recyclable waste and failed 3D printed parts into new spools of usable filament in a single process and relieve the user from conversion inconvenience.

II. Methods and Materials

A. System Overview
The device incorporates the multiple stages in a compact design standing 0.48 meters tall and 0.83 meters long. It is driven by a 120VAC motor that is used to turn the shredder and extruder of the system via a belt-pulley drive train. Material is introduced into the shredder where steel blades grind the material into smaller-sized particles for optimal heating. They are funneled into an extruding barrel that uses a tapered screw to transport material through multiple stages of heating in preparation for extruding. Once material is at optimal melting temperature, it is extruded through an extruding nozzle and coiled onto a spool for 3D printing use.

B. Shredding
The shredder is made from Ultra-Strength High Carbon steel and controls particle sizing through a combination of blade design and a particle sieve. Until the particles are reduced to a size small enough for heating, they collect in a metal sieve and are picked up by the rotating blades. The shredder produces a torque of roughly 50.83 N-m to handle thicker plastic containers used to hold common household goods.

C. Heating and Extruding
The material is transported to the extruding nozzle by an auger rotating at 70 revolutions per minute (RPM) within the heating barrel. To avoid pressure build up, the auger contains a tapered, conical center. This eliminates air bubble entrapment that may negatively affect the final product. Heating of the material is carried out using five heater bands placed along the extruding barrel. Barrel temperature
is monitored using a thermal coupler that communicates with a proportional-integral-derivative (PID) controller for any temperature adjustments which are fed back to the heater bands.

D. Coiling

The coiler consists of three main parts, the spool, traversing mechanism and the cooling fan. As the filament exits the extruder it is cooled and guided onto the spool via the traversing mechanism. This mechanism ensures that the filament will be wrapped around the spool with no worry of entanglement. The spool can then be removed from the bracket for use with a 3D printer.

G. Environmental and Economic Impact

With only 25% of plastic produced in the U.S being recycled and 62% of Americans claiming a lack of knowledge prevents them from recycling correctly, this device can help alleviate the environmental stress on our planet caused by plastic waste[1]. The Recyclops also helps lower the cost associated with 3D printing. Where the average price of a spool for filament is $20, operating this device using recyclable plastics can lower it down to $0.10 per spool making 3D printing a cheaper hobby and tool for industries [3].

III. Conclusion

In all, the Recyclops clears a path for new ideas and interests in the additive manufacturing industry to grow. By establishing a new way to encourage correct recycling habits and incorporating multiple conversion stages into an easy to use, compact design, its implementation will have economic, environmental, and societal impacts

Work Done by Others

Some design tips and research was provided by the non-profit organization Precious plastics and their website which helped advance the team to achieve optimal results in a shorter time frame [2].

Acknowledgement

We would like to express our thanks to our faculty advisor Iman Salehinia and our TA German Ibarra for motivating the team and leading the team in the right direction. Both served as great mentors for the project and offered insight as to what is expected in industry.

References


Abstract—The goal of this project was to provide a solid foundation for the development of a directional control valve operated by solenoids to open and close four independently controlled poppet valves. Simulations were performed to model a Yuken proportional control valve; this provided a way to simulate different parameters before or without physical testing. Data compiled from the simulations will provide valuable information leading into the testing phase and prototype phase for future groups continuing to improve this concept. Simulations proved to be successful in modeling the Yuken valve and demonstrating actuation using a bucket arm. Further developments led to more accurate results, closely modeling that of the Yuken valve. Further improvements can be made to the simulation and concept in the future.

Keywords—control; valve; hydraulics; simulation; solenoid

I. INTRODUCTION

Hydraulic valves are integral in controlling the flow of fluids in hydraulic/pneumatic pump systems, generally directing the energy source by controlling the path in which it is taken; often they are utilized in engines, directing oil/fuel flow. However, there is one major drawback from using this type of valve: fixed spool geometry. For each application of a particular hydraulic valve, specific orifice geometries are used and must be machined for their specific application, often times making them impractical and cost ineffective.

Situations where orifice sizes must be changed to affect hydraulic/pneumatic flow require a more effective method that cuts out the machining process and is applicable to a variety of situations where orifice geometry differs. An example is a four-way spool valve that controls the flow between pumps between a cylinder and tank. Orifice size restricts versatility of this particular valve, and overall efficiency. Replacing this with independently controlled valves (meter-in/meter-out approach) would greatly increase the applications of one particular four-way valve [1]. Although this is not a new approach, it is relatively untested with many improvements that can still be made. Several companies linked to manufacturing and engineering have come out with patented variations of independently controlled valves with varying success. The uses for this type of hydraulic system would greatly benefit a variety of fields/areas such as medical, construction, agriculture, etc.

The general theory behind independently controlled valves involves electronically controlled solenoids that control orifice size and flow rate. Sensors will pick up on changes to orifice size that need to be made and to send/receive signals from the user via programs. This method may be more expensive, but it will be more effective since the program can potentially be changed instead of replacing the entire valve system for a different application.

Figure 1. Independent metering valve concept. Each orifice of the valve is independently actuated and its metering profile is determined in real-time control software.

II. METHODS AND MATERIALS

As described in the introduction, this four-way valve is capable of eliminating the need for resizing orifices and creating a regenerative circuit in its third position (Fig. 2). Ideally, the entire process could be automated where the valve responds to stimuli such as internal pressure and applied load, changing the orifice size based on the output needed. This is done using solenoids that energize to open certain ports; the amount it opens depends on the amount of current flowing through the coil.

Figure 2. Hydraulic circuit of Yuken valve and each position
A majority of the progress made this year was centered around the simulation of the valve concept, modeling similarly to the directional control valve donated by Yuken. Programming was done in Mathworks Simulink, which has components that hydraulic systems would have (e.g. pressure relief valves). Creating the circuit to behave like the Yuken valve was a difficult process due to a lack of key components in Simulink to model after components in the Yuken valve. However, despite this setback an accurate representation of the valve was created in Simulink (Fig. 3).

Figure 3. Hydraulic circuit in Simulink that can actuate a bucket arm. The center block structure represents the Yuken valve system.

Future groups will be responsible for adjusting the simulation as they see fit, and testing the Yuken valve at a testing facility to compare the results of pressure drop versus flow rate to the Yuken data, as well as test the responsiveness of the solenoids, open/close times, etc.

III. RESULTS

Simulink is capable of producing a variety of useful data. One such example is the displacement of the valves controlled by the solenoids “a” and “b” (Fig. 4). The flow rate through these solenoid operated valves can also be measured (Fig. 5). There are many more measurements that can be obtained from Simulink including data that can be compared to Yuken data.

Figure 5. Flow rate through solenoid operated valves “a” and “b” over time.

IV. DISCUSSION

Based on the results, it can be seen that the simulation acts similarly to how a real valve would behave. However, it is important to note that any simulation will not be exactly like testing the actual valve. In fact, the results would most likely be significantly different due to uncertainty. Simulink can account for friction coefficients and other sources of energy loss, but not the unpredictability of fluid flow in real-time. There were several aspects of the Yuken valve that could not be accounted for in the simulation, which would also skew direct data comparisons between the two.

V. CONCLUSION

As it currently stands, the simulations have proven to be successful in creating a stepping stone for future groups in continuing the development of this concept. Because of the inability to include certain parameters of the Yuken valve in the simulation, arbitrary values had to be used. If this can be accounted for, the simulation would be even more reliable. Even with this setback, the simulation provides a very useful method of testing new ideas safely before applying them to the real world.

If future groups are able to build off of the simulation and bring the idea to fruition, it could lead to improvements and breakthroughs in a concept that is fairly new.

ACKNOWLEDGMENT

Special thanks to the faculty advisor overseeing this project, Dr. Ghazi Malkawi, the one who compiled data for the project proposal. Additional expression of gratitude to Yuken for donating a valve for testing purposes, and Matthew Kleszynski, the teacher’s assistant, for his support and guidance.

REFERENCES

Synthesis of Ammonia for Thermochemical Energy Production

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Abstract —
This project aims to examine the feasibility of an Ammonia battery in terms of power generation and storage. Current battery technology has held back the adoption of renewable energy technology’s primarily due to low energy density. Ammonia thermochemical energy storage (TCES) used in conjunction with concentrated solar power plants allows for the collection and long-term storage of power generated from the sun. This is accomplished by leveraging the heat from the sun to split the Ammonia molecules into its base components. These elements can be stored and later recombined in an exothermic reaction generating temperatures sufficient for steam powered turbines. A simulation of this technology was constructed to aid in the development of an Ammonia TCES. The simulation described below achieved an efficiency of 10%.

I. INTRODUCTION
The primary purpose for an Ammonia thermochemical energy storage system is to increase the practicality of solar energy by allowing for long term storage and global distribution of the resulting power. This will be accomplished while decreasing the cost per kilowatt-hour of electricity below the cost of fossil fuel generated power, thus making it economically viable. While the cost of solar panels has plummeted over the last two decades, battery technology has yet to make any significant improvements, as lithium batteries have extremely low energy density, about 1% that of liquid fuels. Current Lithium technologies achieve an energy density of around 250 Wh/kg while gasoline is 12,700 Wh/kg. [1] Ammonia TCES will help close this gap with an approximate energy density of 5,200 Wh/kg, 20 times that of Lithium ion batteries. [2]

A computer simulation of an Ammonia thermochemical energy plant was simulated in Aspen process simulation software. This software is used to test and modify system designs in a rapid and cost-effective manner. This simulation will aid in the development of a complete Ammonia TCES system. The user will enter desired features for the system and the simulation will run calculations on the rest. Simulation allows for the most efficient system to be designed without the need for building scale models in a lab setting.

II. SYSTEM DESCRIPTION
The model created in Aspen Plus V11 is to be used a tool for anyone who is trying to design an Ammonia based thermochemical energy storage plant. The system is built as an open-loop system due to Aspen’s inability to cooperate without a material stream in. The model can be split into three sections: the decomposition block, the synthesis block, and storage. The decomposition block, shown in Figure 1, consists of a reactor, valve, heat exchanger, and a pump. In order to get a compatible energy density out of Ammonia, the pressure needs to be about 200 bar. The heat exchanger is used to transfer the excess heat from the product of decomposition to the reactant. The decomposition of Ammonia is an equilibrium process that must be overcome by temperature and pressure. The addition of a catalyst increases the rate of this process, but Aspen does not use catalysts. The valve of the block is to relieve the pressure built up during decomposition.
The synthesis block, shown in Figure 2 with the storage tank consists of two heat exchangers, a pump, a reactor, and a turbine. The heat exchanger, pump, and reactor have the same job as the decomposition block. The extra heat exchanger allows the energy created from the exothermic reaction of creating Ammonia to be utilized for a turbine. The turbine is then turned by the steam. The storage is a tank that will store the Ammonia and Nitrogen-Hydrogen mixture. The Ammonia will be in a liquid state while the rest will be gaseous.

III. RESULTS

The model designed was validated by following the system created in the source called Techno-economic evaluation of solar-based thermal energy storage systems (3). In this source, the goal was to replicate the heating of water into steam with the temperature of 430°C and a pressure of 10MPa. This source was able to turn that water into 190MW of energy. The other parameters are the 275°C the nitrogen-hydrogen mixture is before the synthesis reactor, the input Ammonia before decomposition is 950°C and 20 MPa, and a mass flow rate of 3.17*10^6 kg/hr. This Aspen model achieved this goal. The turbine does not produce 190MW, but the water does achieve the temperature and pressure required.

IV. CONCLUSION

A model was created in a program called Aspen to act as a tool in designing a closed-loop thermochemical energy storage system using Ammonia. The tool has been validated through a paper showcasing a closed-loop system. The battery of the system will be utilizing the endothermic decomposition and the exothermic synthesis of Ammonia. This tool should allow a group to simulate and help prepare in designing a closed-loop TES system. Ammonia being used as a source of energy would allow for long term storage and global distribution of the resulting power. This will be accomplished while decreasing the cost per kilowatt-hour of electricity while being almost entirely closed loop. This would allow for a better means of storage of solar energy.

ACKNOWLEDGMENT

We would like to thank Dr. Tariq Shamim, the Chair of the Northern Illinois University Mechanical Engineering Department, Curt Steele, the Technical Services Coordinator for NIU and Sandhya Chapagain, class TA.

REFERENCES

Abstract—In the age of climate change caused by the excessive use of fossil fuels, there has been an increase in demand for reducing the use and dependence on fossil fuels. While the shift to other energy sources can already be seen in the automotive industry, the aerospace industry is facing additional challenges. Currently, the limiting factor is the state of battery technologies available, as the specific energy of batteries is much less than the specific energy of jet fuel. Calculating the energy requirements for a flight is vital to estimating the mass of energy storage material required for the flight to succeed. The purpose of this tool is to calculate the energy requirements for a flight and applying it to the gas, electric, and hybrid powertrains to predict the mass of fuel or batteries needed.

I. INTRODUCTION

Over the past few decades, the abundance of carbon dioxide in the atmosphere has been rapidly increasing [1], with transportation industry being responsible for 22% of global greenhouse gas (GHG) emissions [2]. Aircraft, on average, generate about twice as much CO₂ per passenger per kilometer than cars, and about 20 times more than trains [3]. The need for reducing the dependence of the aerospace industry on fossil fuels is clear.

The purpose of this project is to create a tool for engineers to approximate the mass, costs, and GHG emissions of an aircraft with three different powertrain systems: gas, electric, and hybrid. To solve the aircraft dynamics and the power requirements, Aircraft Power Requirement Efficiency Calculator (APREC) has been previously created in Microsoft Excel. Excel was chosen for its simplicity and ease of data presentation. In its original state, the tool was capable of calculating the power requirements for gas powered aircraft, with minor bugs and errors.

The purpose of this project was to expand the functionality to electric aircraft and hybrid aircraft, add optimization functions, and a user interface.

II. METHODS

A. Aircraft Dynamics

The flight profile is split into 7 phases: takeoff, departure, ascent, cruise, descent, approach, and landing. Each phase has a set of specific parameters and conditions which affect the thrust requirements. Forces are solved for from free body diagrams and discretized with respect to time. The forces and kinematics are solved at each timestep, from which power requirements can be derived. Mass flow rate of fuel and battery discharge characteristics are solved. The data fuel flow and battery discharge data is summed over time intervals to calculate the total fuel mass and battery mass requirements.

Changes were made to the original APREC tool with regards to dynamics calculations. Main improvements include lift coefficient calculation, descent, approach, and landing reformulation, and changes to aircraft parameters and flight profiles.

Several formulas were adjusted to increase the accuracy of derived aircraft and flight parameters. The new parameters are able to reproduce more accurate results.

The reformulation of the descent and approach phases were necessary, as previously the aircraft had negative pitch, equal to the descent angle. The flight profile has been recalculated to keep the aircraft leveled while the flight velocity and thrust are decreased to reduce the altitude.

The modifications to the landing phase added reverse thrust. Previously, the only forces slowing down the aircraft were drag, rolling friction, and braking friction. With the addition of reverse thrust, the calculated landing time is more accurate than previous iterations.

B. Battery and Hybrid Implementation

The main purpose of the APREC tool is to be able to compare the potentials, costs, and GHG emissions of different powertrain types. The aircraft dynamics of the gas, electric, and hybrid models are the same, therefore the only changes needed are power consumption and delivery calculations. The battery pack is composed of individual battery cells arranged in series and parallel. The battery pack had to satisfy voltage, charge, and maximum discharge requirements. The voltage requirement can be satisfied by adding batteries in series arrangement. Charge and discharge current can be increased by adding more batteries in parallel configuration. The product of the number of batteries in series and parallel yields the total number of batteries, which then can be used to calculate the total mass and costs of the battery pack. Energy requirements are used to calculate the GHG emissions from generating electricity to charge the batteries.

The hybrid powertrain is modeled as a combination of gas and electric models. The user has control over the gas-hybrid split for each phase. A 50% electric and 50% gas hybrid model means that half the energy required will be delivered via fuel, and the other half via battery power.
C. Optimization Scripts

Multiple scripts have been added to the Excel tool with the help of Visual Basics for Applications (VBA). The purpose of the main optimization scripts is to adjust the initial fuel mass, battery mass, or battery parameters. A few minor scripts have been added to simplify the tool for the users. Simple scripts such as setting the payload to the maximum allowable, and to reset previously optimized parameters to default values.

Initially, the aircraft’s fuel mass is set to its maximum value. The script reduces the initial value by a small percentage until the fuel life at the end of the flight is near a desired value. The fuel life is calculated as a ratio of current fuel mass to the maximum fuel mass.

The battery mass optimization adjusts the initial battery mass of an electric aircraft. The initial battery mass is set equal to the maximum fuel mass. The tool then calculates the battery mass required for the flight. The calculated battery mass is then substituted as the initial battery mass of the next iteration. The loop ends once the difference in battery mass between two consecutive iterations is less than 1%. Since no more battery mass needs to be added, the aircraft can complete its flight with the calculated battery mass.

Another script was added to optimize the battery properties. Certain flight profiles are not possible to be completed with batteries, as the battery mass never converges to a value. For these cases, a script was added to increases battery cell properties like voltage, charge, and maximum discharge current. The battery mass is set to the maximum fuel mass for the aircraft and fixed through the optimization process. The optimized battery parameters are displayed to the user for comparison against the initial parameters.

D. User Interface

A user interface has been added to the tool using VBA. The interface simplifies the tool for the user to limit the necessary inputs and outputs, with selected outputs shown in Table 1. All inputs but the Aircraft Type and Trip Distance can be different for System A and System B to compare different flight profiles. The addition of the interface reduces the amount of unnecessary data displayed. Navigating the spreadsheet is no longer necessary to use the tool and to see the results.

A plotting function has also been added to allow the user to view trends in variables as functions of other variables, as seen in Figure 1. The plotting function generates plots of variables and display a table of datapoints below the table for more precise analysis. Both System A and System B are plotted at the same time to show the differences between the two systems.

III. CONCLUSION

The APREC tool has the functionality of comparing different powertrain options between gas, electric, and hybrid. The aircraft dynamics have been corrected and improved over the previous version. Battery calculations have been implemented to design appropriate battery packs from battery cells for different flight profiles. A hybrid model is also implemented to split the power requirements between gas and batteries.

Table 1: Interface inputs and selected outputs.

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft Type</td>
<td>Mass of plane</td>
</tr>
<tr>
<td>Trip Distance</td>
<td>Velocity</td>
</tr>
<tr>
<td>Battery</td>
<td>Fuel/Battery Mass</td>
</tr>
<tr>
<td>Motor Voltage</td>
<td>Fuel Burn</td>
</tr>
<tr>
<td>Payload</td>
<td>Fuel Life</td>
</tr>
<tr>
<td>Electrical Efficiency</td>
<td>Fuel/Battery Cost</td>
</tr>
<tr>
<td>Engine Efficiency</td>
<td>CO₂ Emissions (Fuel/Electricity)</td>
</tr>
</tbody>
</table>

VBA scripts have been added to optimize the flight profiles. The initial mass of fuel and batteries can be calculated through an iterative process. In case the battery mass cannot be optimized due to divergence, the battery cell properties can be optimized to satisfy flight parameters.

A user interface was added to simplify the user experience by limiting the displayed inputs and outputs. A plotting function has also been added to simplify the analysis of trends.

Fig 1: Data plotter

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REFERENCES

Treadmill Belt Tester

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I. Abstract:
The purpose of this project is to design a test fixture or suit of text fixtures to replicate the real-world stresses that a treadmill belt experiences. This will help our client to evaluate and compare future belt designs faster and without any public exposure. Our optimal design is based on simplicity and efficiently that would meet the requirements that our client sat for us to follow.

II. Introduction
Life fitness had multiple issues with their design that would make it unrealistic thus, unreliable data to make any changes in the belt’s material. First of all, feet were constantly to hit the same spot. Feet were also getting dragged by the belt. We used data collected by our client to determine what type of motor we will use with what characteristics.

According to the speed data collected we have chosen the most suitable motor for this. The motor is 2.5 hp (1.9 kW) 48 volts

III. Mechanical Design
Our design is based on having two motors for each foot; the main idea is to get both feet to walk with the treadmill like a real human in terms of changing speed according to the belt. A coupler is attached to the shaft of the motor to attach an encoder that would provide speed and positioning of both feet. In order to match the speed of the feet with the belt we designed a wheel that would be constantly rolling on the belt with an
encoder attached to it that would send
signals to the Arduino to change speed of
both feet based on data collected. Both feet
are going to move using a chain, a threaded
bolt is used to tighten up any slake on the
chain. A bicycle hub will be used to rotate
the chain attached to long slot for any high
adjustments as well as having a disc brake to
stop both feet.

IV. Safety Precautions

It’s important for us to keep the user and
people surrounding the device safe from
any danger that a break down could
cause. Therefore having acrylic plates is
essential to keep everybody safe, the
fixture was cover with acrylic plates
from the front and both sides in case the
chain broke down. We attached optical
switches to control how far feet are
crossing the rails and incase one
foot is to get through these switches it
will send a signal to the disc brake to
apply an emergency brake in order to
stop the foot from reaching out to either
the end or the front of the fixture and
cause any damage.

Figure 5: Optical Switch

V. Conclusion

The design is not yet to be perfect and
ready to build. But we can say that we
have learned a lot through this semester
as well as made a lot of progress in
terms of getting it to meet with our
client’s requirements in terms of
replicating some of the real life stresses
applied to the belt when using the
treadmill.

VI. Reference

[1] SKU: ATO-BLDC 2300R3
(https://www.ato.com/3-hp-2-3-kw-24v-
brushless-dc-motor ).

[2] Pierrot, F., Reynaud, C., & Fournier,
A., "DELT A: a simple and efficient
parallel robot." Robotica v8(2):105-
109,April1990,
(https://www.cambridge.org/core/journal
s/robotica/article/delta-a-simple-and-
efficient-parallel-
robot/CC452596DC61FFC0F2E8CFF0
ACE44994).
Magnetorheological Fluids or Electrorheological Fluids: Applications to Occupational and/or Rehabilitation Exoskeletons

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Abstract - The leading cause of injury in the manual labor force is overexhaustion and the use of exoskeletons has been an effective solution to this problem. Wearable exoskeleton technology has increased rapidly in technology and with that comes an increase in potential uses and popularity. One area that has been lacking in this technology is the ability to have an easily adjustable exoskeleton joint. The application of a rheological fluid and its ability to change viscosity with a change in voltage is used as an effective solution especially for rehabilitation where very fine adjustments to resistance are needed. Rheological fluids have been used in an increasing amount over recent years. With no commercially available rotational MR fluid dampers on the market, development of a joint was necessary.

I. INTRODUCTION

Injuries often occur to employees who spend a lot of time doing physical activities such as lifting, pulling, pushing, holding, and carrying. Over time, these activities being performed repeatedly lead to stress on muscles and joints which can cause overexertion injuries. Wearable exoskeleton technology can be improved and optimized for these purposes by implementing dampers in the joints using magnetorheological (MR) or electrorheological (ER) fluids. These fluids are unique because applying a magnetic or electric field changes their apparent viscosity. These fluids can be finely adjusted based on the power of the electromagnet being used to activate the fluid.

II. MECHANICAL HOUSING

A. Fluid

The use of Magnetorheological Fluid (MR fluid) within the joint is to control the amount of rotational resistance that can be applied by the fluid. This joint uses MR fluid, or MRF, this is a fluid consisting of three components. The three components are oil, metallic particles and a binding agent which is used to keep the combination of oil and metallic particles as an evenly mixed fluid. This fluid is used because of its ability to change viscosity. The fluid changes viscosity based on the strength of the magnetic field applied. The change in viscosity happens because the metallic particles within the fluid follow the magnetic field lines when the magnetic field is applied [Fig. 1].

![Fig. 1 Demonstrates how the MR fluid changes viscosity. When a magnetic field is applied, the metal particles suspended in the liquid conform to the magnetic field lines.](image)

The magnetic field strength will be varied based on the power being supplied to the magnet.

B. Housing

The housing is attached at the elbow of the exoskeleton, attaching the upper and lower arm frame to provide support in holding activities. The housing needs to be small and lightweight so as to not reduce one stress and add another. In order for the housing to be small and be attachable at the users elbow or knee, the joint had to be circular. This meant that the joint had to dampen rotational motion, different from past applications where the fluid was used in a piston like
damper with a center shaft moving linearly within a MR fluid lined cylinder. The rotational joint, similar in size and shape to a large hockey puck, can be attached to either the knee or elbow joint of an exoskeleton with ease.

The housing design was based on using MR fluids changing viscosity. The change in fluid viscosity is proportional to the force required to move the surface along the fluid layer. Having a fluid with an adjustable viscosity allows for a constant surface area at the fluid level. Thus, the changing viscosity alone will change the drag force caused by the fluid. This acts similarly to an adjustable friction between two plates rotating in opposite directions.

![Fig. 2 Graph of the change in force versus the change in voltage supplied to the magnet](image)

### III. VARIABLE POWER SUPPLY

The magnet used to apply the required magnetic field to the MR fluid is a 24 VDC round solenoid electromagnet. This magnet was chosen because its magnetic field is strong enough when rated voltage is applied and the size and shape allow it to easily be placed directly into the center of the joint. When the fluid is placed in the magnetic field at 24 VDC, the viscosity is changed to its maximum. When the supplied power to the electromagnet is decreased, the field strength decreases proportionally. When the field is applied to the fluid and the field is varied, the viscosity of the fluid also varies proportionally with the strength of the field and the power supplied to the magnet.

The variable effect of the power supply is created by a simple electric circuit utilizing a potentiometer. The power supply provides a constant 24 VDC output. Using the potentiometer in series with the electromagnet allows for variation of the supplied current to the electromagnet between 0.63 and 1.33 amps. This range allows for maximum variation of the viscosity of the fluid.

The electrical components of the system will be powered by a 24 VDC Lithium Ion rechargeable battery. The battery will not be integrated directly into the joint system but will be wired to the joint and mounted separately in a box along with the on/off switch and the dial for user resistance control. The selected battery is ideal because of the high power output capabilities, compact size, and long battery life between charges (22.4 Ah/82.88 Wh).

### IV. CONCLUSION

The MR fluid exoskeleton joint utilizes magnetorheological fluid in a previously underexplored way. The MR fluid will be used to provide variable resistance to an exo joint, providing assistance in occupation lifting and resistance for rehabilitation purposes. The joint housing the MR fluid is 3D-printed and designed to maximize the fluid’s variable-viscosity properties to provide the best increase in resistance possible. The user will have complete control over the resistance of the joint given a simple switch and control dial which allows them to turn the resistance off at any time or vary it however they want from no added resistance to maximum.

### ACKNOWLEDGMENT

Thank you to Dr Donald Peterson, Justyna Kielar, and Simon Kudernatsch.

### REFERENCES


Abstract— We developed a lightweight, easy-to-use and smart unit to be attached to military combat helmets and provide comprehensive information about the battlefield for military personnel in real time. The device takes advantage of 3 MEMs microphones placed in specific spots to maximize operations of the system. When detection of a shot is registered the system locates the angle relative to the soldier position. An LED in the array will light up the section where the shot originated from, this provides vital information to our troops in combat situations and is the key to their success. A battlespace 360-degree image is taken with four CMOS cameras located around the housing; these images will be available for intelligence review for further operations. All information is routed to the Raspberry-Pi with a Graphical User Interface for information. This device is meant to assist in combat operations in many climates and situations for our Military.

I. INTRODUCTION

In the modern environment, there is no telling where dangers can come from. This can affect the modern soldier in numerous ways while on deployment. There are many stresses and conditions that harm the efficiency and morale of our soldiers. The Smart Combat Helmets’ goal is to reduce mortality rates and increase the effectiveness of our forces when deployed.

This device will be thin, lightweight, and meant to attach easily over existing helmets currently used in the military. One key characteristic of this device is to keep it simple so it can effectively operate in multiple environments. Keeping the unit simple allows ease of production and minimal implications that can arise in combat situations. This is meant to assist troops in combat while being unobtrusive enough that they will never be bothered by the unit. This has led to the design shown in Fig 1. The high profile allows the soldier a full view of the battlespace and provides assistance when needed.

The frame allows the cables to run through to the back of the unit. This is where the Raspberry-Pi is stored and protected. The inside portion of the frame is curved to sit properly on the helmet. The unit opens by pulling the pin seen on Fig 1. and Fig 2. Once it’s pulled, the helmet has a hinge that allows the cables to pass through while being protected from the outside elements. This also allows the user to take off the unit without damaging anything.

The key feature is sound localization, the entire system works based on the frequency of the sound a travelling bullet makes. Enemy shots can be identified by their frequency and their location will be shown by a single LED in the general direction of the shots origin. The system relays the analog signal output to the Raspberry-Pi to evaluate the frequency response between each MEMs microphone. Using this information, an angle is determined followed by an LED that points to the shot’s origin.

The unit has four cameras around the device, each placed in a certain position to provide a 360 degree view. Each is stored inside the housing with open ports as seen in Fig 1. and Fig 2. Having a wide field of view camera system allows documentation of positions and locations for future advancements in zones of operations. The system operates when a shot is detected, the camera array will start. Each camera will take a photo of the battlespace. As shots are detected the cameras will activate while storing all the data.

With more knowledge of combat situations, the Smart Combat Helmet will be modified and changed over time. This device will also change with the evolving military forces’ needs as well as adhere to all regulations provided by the Department of Defense.
II. METHOD AND MATERIALS

A. Prototype Design

The Prototype design can be determined from the above Fig.4. The sound is an impulse response which the MEMS microphones will pick up and send to the Raspberry Pi. The Raspberry Pi will convert the digital signal to an analog output and determine which microphones have the best two impulse responses. This analog information will be submitted to the noise localization coding and used to calculate the last angle of the triangulation theorem. With this computed, the program modules will split into two functions. The cameras will activate and capture the surrounding area and store the images into a folder that can later be extracted by the user to further examine the battlefield scenario. The other part of the program module will relay the localization coding into the Degree of Freedom program which will designate a specific LED to light up corresponding to the calculated angle.

B. Raspberry-Pi Interface

The Raspberry-Pi is the main component of this system. This device is used as a Graphical User Interface that allows for many applications to be used simultaneously. For this interface, it is used to store images that the CMOS cameras have taken into a specific file that can be extracted for further investigation. The program that is used to save all coding aspects of this system is called “Thonny”, a Python Integrated Development Environment. This IDE allows the user to create the coding required to translate the digital signal for the rest of the program to understand the syntax.

III. Results

Using recordings of various bullets passing, frequencies corresponding to different bullet calibers were found by running the recordings through a spectrum analyzer.

Theresulting graphs are shown below in Fig 5:

![Fig 5. Passing Bullet Spectrographs](image)

From these graphs, it is shown that each caliber has distinct acoustic behavior and a maximum frequency. These differences can be used to identify specific bullet calibers and types of weapons. Using this information, friendly and hostile elements can be distinguished, and an estimate of armed hostiles present can be found.

Using an IVMech multiplexer board, it was possible to run 4 cameras using the Raspberry-Pi. Shown in Fig 6. are images taken using the 4 cameras. Images saved by the device can be used to get more detailed information when reviewing battle data that can be helpful in the future.

![Fig 6. Multiplexed Camera Images](image)

IV. DISCUSSION

As this system is currently completed for phase one, it can be further improved by implementing more technological devices to increase the capability of this system. Such implementations can include: an LED Screen displaying the information of the position, a geographical coordinate system and design of a custom PCB board to accomodate all components necessary.

V. CONCLUSION

Upon completion of the system, this device will help soldiers in combat to increase survivability ratings and better evaluation of the battlespace after image extraction. Ultimately this device should be used as an assist and is meant to be out of the way when not needed.

VI. ACKNOWLEDGMENT

We would like to offer our thanks to our advisor Dr. Mohammad Moghimi for allowing his guidance to develop this project. Thank you to the following people as well: Todd Durham, Matt McCoy, Jacob Serena and James Davidge Sr. for their help in accomplishing this project.

VII. REFERENCES


Automated Traffic Signal Snow Removal System
Team 65
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Abstract - This paper describes the use of a heating element in order to keep snow from building up on the surface of an LED traffic signal. This product provides an easy way of improving existing LED traffic signals and it can be easily mounted to them. It provides enough heat to keep the surface clear during the harsh winters of the northern regions around the world. The device will melt snow in no longer than 10 minutes. The materials for the device are cost efficient and should be easily installed/uninstalled.

I. INTRODUCTION
After the invention of cars, the traffic signals were created. Traffic signals needed to command the flow of traffic since it had become a problem in bigger cities. First traffic signals used gas to power them. Then, they converted into electricity powered. Throughout the years the traffic signal had used halogen bulbs to emit the light. Therefore, the use of those bulbs became a problem to cities since it used high amounts of energy. Why was it a problem now? The problem arose since the car population around the globe increased exponentially. For this reason, cities had to install multiple traffic signals in cities. Therefore, they needed to come up with a solution to control the energy wasted. The solution was to introduce a new type of bulb/light. The LED lights became the perfect alternative. They were far more potent than incandescent bulbs, and they did not use as much energy. So, after the Energy Policy Act of 2005, traffic signals were mandated to use LEDs.

After the addition of LEDs to traffic signals, a new problem arose. The problem was that LEDs do not emit enough heat to melt the snow at the surface of the lens. Therefore, people tried to solve this arising problem by using deicing chemicals before a storm would hit. The deicing chemicals provide a protective layer to the surface of the light’s lens so when the snow hits it, it falls since it can’t grip itself to it. But when the snow becomes wet or too heavy, then this deicing chemical does not work as it should. So, there had to be another solution.

The new solution was to create a lens for the traffic signal that could heat itself up when necessary. This is where this project comes into play.

II. MATERIALS AND METHODS
There were two types of heating elements. Both types will be applied to a 1/16 in thick sheet glass. The first type is a heating wire that is fused into the glass. The second is an ITO film that is applied to the top of the sheet glass. Both will be placed into the heating element container. Inside the container the heating element will be connected to a female connector with a wire.

When designing the heating element container some conditions needed to be considered. The design must be easily replaceable and compact to fit. Due to the location of traffic light’s the container must be rugged enough to deal with harsh environments. As such the following design was chosen.

It was decided that the heat element container will be made of aluminum alloy 5052 as that has a high fatigue strength compared to plastic. To improve safety from burns an insulated rubber will be applied between the contact area of the heating element and container. On the bottom edge of the container a thin layer of rubber will be applied to prevent water from entering the system. For proof of concept the container was 3D printed with PLA.

To allow power to run to the heat element a slight modification to the traffic light lid must be made. Some holes are added to the traffic light lid. These holes will allow for the male connectors to be attached. The female connector will be applied to the container of the heating element.

The system is controlled by a microcontroller, in this case an Arduino Uno. The way the system operates is there will be a Temperature Sensor (LM35DZ) mounted on the outside of the traffic light that senses the ambient temperature. If the temperature is below 0 degrees Celsius, it goes to the next phase, otherwise it keeps sensing.

Next, a Photocell (VT43N1) senses light to determine if the lens is covered. If the Photocell senses some light from the LED, then the lens is clear. If it senses a lot of light from the LED, that means the lens is covered because the light reflects off the lens covered in snow back to the Photocell.
The final phase is when the heating element (ITO Film) heats up melting all the snow/ice. The circuit is shown in figure 2 below.

III. RESULTS

While following heat transfer laws, the ITO film was tested having different areas in order to come up with an idea of the heat generated which could be produced. Since this film is conductive, the surface area plays a big role to know how much heat we can provide to the system. Therefore, by using the resistivities for each rate of ITO films there is, the resistance could be calculated. Following equation was used to calculate it.

\[ R = \frac{\text{Resistivity} \times \text{Length}}{\text{Area}} \]

To continue, the next goal was to calculate the power generated by the material. The power was calculated by using the following equation:

\[ P = I^2 \times R \]

The film was tested by using a power source and an oscilloscope in order to get the current measurement. The current flow varies per strip of film. Therefore, for the strip of area 1, the current flow was 0.04 A, and for the strip of area 2, the current flow was 0.12 A. Using these known values, the power was able to be calculated.

<table>
<thead>
<tr>
<th>Rate of Film</th>
<th>Power at A1</th>
<th>Power at A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>99%</td>
<td>0.207</td>
<td>0.829</td>
</tr>
<tr>
<td>97%</td>
<td>0.221</td>
<td>0.885</td>
</tr>
<tr>
<td>90%</td>
<td>0.224</td>
<td>0.896</td>
</tr>
</tbody>
</table>

Table 1: Power of Strips of Films at different Rates

As Table 1 shows, power does increase when our film has a larger area. The film’s power also increases as the rate of the film increases. Therefore, the last step was to find out how much the surface would heat up. According to some derivation of the energy transfer equation, the temperature of the surface was able to be solved by using the following equation.

\[ T_s = \frac{\dot{q}}{2 h A_s} + T_a \]

To further explain the equation, \( \dot{q} \) is the power generated by film, \( h \) is the heat transfer coefficient of glass, \( A_s \) is the surface area of film, \( T \) is temperature, and subscripts \( s \) and \( a \) mean surface and ambient, respectively.

It was discovered that the surface temperatures of the films increase as the ambient temperature increases. Also, the film rated at 90% has the highest of all.

Another study done on the heating element was to use different types of snow to see how the heating element will behave. Therefore, the thermal conductivities of air to ice. Also, the ambient temperature was of -10 °C which is a temperature below the average temperature of states such as Illinois. The power used was of 100 W. This power was measured to be the most attainable for our system. Therefore, Graph 1 shows the surface temperature vs the thermal conductivity. Power used was of 100 W.

IV. CONCLUSION

In conclusion, this system is a great idea for LED traffic signals. The heating element used will help improve visibility of light and will use a low amount of energy since it is activated only when necessary. Also, it has the capability of being installed easily, and being uninstalled easily. This further improves the efficiency of it. Furthermore, it does need more work to be done.

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REFERENCES


Abstract: A Surface Plasmon Resonance (SPR) device is required to find the SPR angle of a metallic surface where the surface has minimum reflectivity of light emitted to it. The project concerns the design and implementation of an optical reflectance measurement system for the characterization of surface plasmon resonant structures. The NIU Electrical Engineering department requires one of these devices for the course known as ELE 421 (Biomedical Sensor Engineering). This should be a portable and modular device which has a large possible range which the angle of incidence can be and the light for this device should be a polarized beam. The device is required to emit p-polarized light, have a low enough weight to be lifted by one person, and be modular so that components of the device that directly relate to the measurements made by the device can be replaced.

1. Introduction

Current devices that can explore the SPR phenomenon are very costly. Lower end devices from NanoSPR cost $5,000\(^1\), and this amount is much greater than the intended $1,000 budget for this project. The most common method to exhibit the SPR effect is through a method called angular SPR in which a predetermined wavelength of light between 400 to 700 nanometers is incident upon a metal sample, usually gold or silver, and the light intensity is recorded at various half angles between 0 and 90 degrees with respect to the sample to obtain the reflectivity dips which correspond to the SPR condition.

Environmental screening, gas detection, and healthcare testing are all modern day uses of the SPR phenomenon. There are also uses of SPR technology in discovering material properties, biosensing, life sciences, drug discovery, and food analysis\(^2\). Thus, there are many areas of research where SPR devices can be useful tools.

2. Methods and Materials

The changing angle is achieved in the device by having two trolleys travel symmetrically along a semicircular rail. One trolley contains a laser and the other contains a detector circuit. These trolleys are motorized and are calibrated to be symmetric on the rail. The device is highly adjustable for many variations of samples, lasers, and receiving circuits (meaning they are interchangeable) and the entire system has easy angular and two-dimensional adjustability. Some other adjustability is possible such as being able to rotate the laser about the fastener which secures the laser clamp and some level of vertical adjustability in the detector circuit.

This design takes a premade trolley and rail system to assign the travel path but replaces the trolley platform with a 3D printed version that is appropriately designed for everything that gets attached to the platform. This new 3D printed trolley base reduces the angle between the two trolleys when they reach the arc center-point of the semicircular railing, from approximately 24 degrees to 21.7 degrees. A visual representation of both the trolleys approaching the vertex of the railing is depicted in figure 1. The ability for the trolleys to get closer to each other at the vertex of the railing expands the maximum angle that the device could measure the light intensity at angles of incidence in the range of 21.7 to 180 degrees relative to the sample.

![Figure 1: 3D model of the components of the device including baseplate, rail, trolleys, motors, and power supply at the minimum angle condition](image-url)
The device uses a homemade light detector circuit out of basic electronic components such as a photodiode, amplifiers, resistors and capacitors. This minimizes the cost of purchasing a photodetector from a vendor with an added benefit of positioning the photodiode in a custom location. This photodetector is modular so it can be replaced in the future with any other photodetector that meets similar dimensions.

An Arduino Uno microcontroller controls the signals that are sent to the stepper motors and the output of the photodetector circuit and motor encoders. The motors themselves allow for a resolution of 400 steps/revolution and the encoders give the ability to track the number of steps that the stepper motors take. This can be incorporated into the Arduino’s program to calibrate the trolley positions for higher device accuracy. The stepper motor driver known as the L6208 is used to decode pulses received by the Arduino as directions for the stepper motors to rotate clockwise or counterclockwise and allow for micro-stepping to achieve greater resolution in data capturing.

3. Results and Discussion

Using a plotting function in LabView (or equivalent program), the angle between the trolleys to the sample (angle of incidence) versus the intensity of light detected can be graphed. This graph should show a large dip where the shallowest point is considered the SPR angle of incidence. The graph can be viewed in real time by the Arduino sending serial data to the controlling program such as LabView. Through such external program, the data from this graph can be saved into a file that is on the computer that the Arduino is connected to. There are also some external safety procedures that are implemented through the Arduino via physical buttons or switches that send interruption signals to the Arduino to stop certain parts of the program depending on which interrupt was activated. In the user interface there are also on-screen buttons to stop certain actions of the program from occurring.

4. Conclusion

The device designed is a cost-effective solution for Northern Illinois University and can be used as a tool for students in the course ELE 421 to get hands on experience of being able to view the SPR phenomenon in real life and not just in videos and simulations. Secondly, it can be used as an experimental unit for faculty research. Lastly, the design of this device could also be a useful reference for other researchers building or working with SPR devices.

Figure 2: A representation of the assumed output graph for the designed device

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References

Robotic Injection Pump Tester and Leakage Automated Detection

Northern Illinois University and SKF Sealing Solutions

Ismael Braido, Jacob Hall, Ben Shapiro

Abstract - The objective of this project is to design and produce a device that can automate pump testing and leakage detection. The Robotic Injection Pump Tester or RIPT includes an Arduino microcontroller, a fishman fluid dispenser, stepper motor with motor control and driver. RIPT has the capability to mimic the way that a technician (Terry) performs a pump testing. RIPT will obtain information accurately and increase the consistency in pump testing while reducing technician workload. LAD or Leakage Automated Detection is comprised of a web camera and a Raspberry Pi kit. LAD is designed to have the capability of detecting the exact moment when a seal fails by capturing the live image of fluid leaking from a dynamic or round static seal and can classify the type of leakage.

I. Introduction

Currently SKF’s technicians perform labor intensive pump testing and face number of challenges when observing the exact moment that a dynamic seal begins to fail at performing its primary function, which is to retain fluid. Currently there is no commercially available technology to detect when dynamic or static seals fail. A technician must look at the seal or fluid levels need to be checked to know if fluid is leaking. The Pump test shows the pumping rates of dynamic seals, or how fast the seal can move the fluid from the dry side to the wet side. Both are done by technicians and can be time consuming. SKF has been developing an autonomous test for since last school year. The pervious team developed a proof of concept and SKF further refined the code the old robot ran on over the summer of 2019 with an intern. The project for the NIU students this year is to further develop the current prototype concept or to redesign the autonomous pump test to a usable prototype. This project could include autonomous leakage observation.

II. Methodology

The team decided to split the project into two main sub-projects. To aid in the development of the project, and ease confusion of the differences. The first half of the school year was dedicated to studying the problem, developing mounts, bracket, the robotic system to move the injector needle to and from the work site. The second half of the school year was dedicated to the robotic vision system and intergrading all the components.

a. Leakage Detection

The Leakage Detection project consists of a Raspberry Pi 4, Pi camera, a touchscreen interface, python GUI and cooling system. The Raspberry Pi 4 is used as the computer to run the python GUI used to detect the leaks, and to send the data sheets to the technicians. The Pi camera was chosen due to the simple attachment to the Pi. The camera can be placed on a multitude
of machines as long it has at least two inches of clearance from the dynamic seal. The team then designed a custom case for the Pi system to allow extra cooling due to the heat that it was producing. The system allows the technician to enter in data specific to the test performed, then tracks the seal with the camera until a leak is detected. After the first detection data is then imputed into an excel sheet and continues to track the leak till a specific end condition is met.

b. Automatic Pump Test

The Pump test consists of the Fishman LDAV automatic dispenser unit, python GUI, Oriental stepper motor, programmable motor controller, and an Arduino. The Arduino is used as a controller to send signals between the python GUI and the Fishman LDAV. The Fishman LDAV is programmed to run specific fluid dispensing programs based on the amount of fluid needed, without drippage and precision to 20 µL. The stepper motor is used to place the dispenser at the lip of the seal and move the dispenser out of the testing area due to the heat produced by the testing machine. The whole program is controlled by a python GUI that can be ran on any windows-based laptop and send all data to the technicians once the test is completed.

III. Results

The team found that the LAD system can perform the tests required from saved videos on laptops. RIPT will be able to perform the Pump test motion over the seal over 20 times without the need of interference of the team. The camera system was able to track a fluid within the first 0.3 seconds that it was present, which is on par with the current technician. The team was unable to test on the VRM at SKF at the time of this report.

IV. Conclusion

The team was successful in the design and building of both the LAD and the RIPT and recommend testing of both systems. Updates to the platforms include the use of an encoder for the stepper motor, a larger Arduino to act as a controller to the Fishman, and a case study on the Fishman LDAV limitations. However, the system is efficient at tracking the fluids and further testing needs to be done to compare the autonomous systems to the current methods.

Acknowledgements:

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Abstract: — IoT and cloud computing are the prime objective of the current design project and development in the field of healthcare. In this project, an attempt is made to enhance the integration of wireless sensor network in IoT environment with cloud computing for health care system. IoT is a dynamic network infrastructure, that interconnects different sensor networks through Internet, acquire sensor data/information, transmit and receives data/information for further processing. The related sensed data/information will be sent for the necessary information exchange together with the design and optimized parameters. Work will involve fabricating a prototype design using an affordable microcontroller system along with appropriate sensors.

1. Introduction

The number of patients that require medical assistance is increasing each day while staff-patient ratio is unbalanced causing issues such as treatment delay that often leads to patient dissatisfaction. Healthcare devices are also complex and challenging to be handled and not readily available in certain parts of the world. Lack of staff and challenges in operating the medical devices not only affect patients in hospital but also cause problems to home care patients that require full attention and constant monitoring. This urges for a development of a new method or technology. IoT devices in healthcare has been the leading solution to help combat this issue however majority of the IoT devices developed today are very expensive and are only capable of performing one task so a more cost effective and versatile solution is necessary. The design of IoTSNPC (Device 68) aims to improve the quality of lives of people without the hardships of constant visits to the hospitals and high costs of simple medical checkups and expensive inhouse health care devices. The configuration of this device creates a balance between weight, cost, and functionality while incorporating safety features with dynamic feedback control.

2. Design Features/Methods

An attempt is made to enhance the integration of wireless sensor network in IoT environment with cloud computing for health care system. This design is going to consist of dynamic network infrastructure, that interconnects different sensor networks through Internet, acquire sensor data/information, transmit and receives information for further processing. The platform is built around a wearable sleeve that will include appropriate sensors connected to a microcontroller and a power source.

A) Microcontroller:

The microcontroller being used for this device is Raspberry Pi 4. It is the ultimate Raspberry Pi, it has up to 4GB RAM, a faster quad-core CPU, support for dual displays at up to 4K resolution, Gigabit Ethernet, USB3.0, wireless LAN, Bluetooth 5.0, and USB-C power.

B) Oxygen/Heart rate sensor:

The oxygen/heart rate sensor for this device is a Wellue O2 Ring Oxygen tracker. This is a ring-shaped Bluetooth sensor that continuously trackers oxygen levels, heart rate and body movement. It has a built-in rechargeable battery that can last 12-14 hours, and it also has built in memory to store information.

C) Blood Pressure Sensor:

The blood pressure sensor used in this device is a using UltraConnect’s Wireless Wrist Blood Pressure Monitor. It is a small, lightweight blood pressure monitor that syncs quickly with the controller. The sensor transmits data via Bluetooth; however, it does not sense blood pressure continuously. The sensor can track both systolic blood pressure and diastolic blood pressure as well as heart rate. It is rechargeable and can last up to 100 uses before needing to be charged again.

D) Temperature Sensor:

Smarttemp is an FDA Approved smart Bluetooth temperature sensor that allows patients to track their body temperature in real time through a computing device using safe low energy Bluetooth 4.0. SmartTemp is 100% waterproof with a sealed battery compartment with no charging or dangerous battery
leakage. Smarttemp is placed under patient’s arm using a soft adhesive patch that feels like tape. Painless removal.

E) LCD Display/ User Interface:

The LCD display used is the 4inch HDMI LCD (H) 480x800 hardware resolution display. It has a 4-inch Resistive Touch Screen Display IPS LCD with HDMI interface, perfect displaying from very wide viewing angle. It comes with 3.5mm audio jack, supports HDMI audio output. Backlight can be turned off to lower power consumption. The user interface used for this device is a simple GUI developed using python coding. It follows a very simple format of displaying the various data readings and displaying the continuous plots of the various reading.

F) Battery Pack:

The Raspberry Pi and Display are powered by lithium polymer batteries by means of the Quimat battery expansion board. The power-on state can automatically detect the load and start the output function, and automatically turn off the output when there is no load. • The size and mounting holes are exactly the same as the Raspberry Pi for easier installation and use. • It's convenient to power on / off raspberry pi via battery switch; • It can last about 9 hours if only pi 3. • The Lithium battery expansion board can be also used on cellphone. • Battery capacity: 3800mAh •Maximum output current: 2A •Output voltage: 5.1V ± 0.1V •Standard charging current / voltage: 2A/5.0V Package included: 1 x Lithium Battery Expansion board (with lithium battery) 3 x heat sink 4 x Gasket 8 x Copper standoff 12 x Screw 12 x Nut 1 x Micro USB cable 1 x Acrylic Case

3.Conclusion

The main goal of this project is to show how important artificial intelligence is to human lives and how significantly improve our lives. The device makes use of multiple wearable sensors capable of reading important vital signs, such as blood pressure, heart rate, respiratory rate, and temperature that communicate information with small computer board, that can then send the information to the cloud wirelessly. IoTSNPC will allow users to have a greater knowledge of their health and allow them to take necessary precautions to improve their health in the comfort of their homes.

4. Acknowledgement

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5. References


Abstract- The SecuriBot is the newest integration to common societal life. As robots get more frequent in society, new inspirations on ways to make tasks easier or more effective arise. A robot focusing on keeping people and their belongings safe creates a new meaning to security system technology carried out within home and industry environments. The SecuriBot is a four-part system with safety and security in mind. Some robotic designs have been created with the intent of creating alternatives to better security systems, however, these designs happen to be quite expensive and lack the security aspects that are incorporated into the SecuriBot’s design.

I. INTRODUCTION

In all times, people have worked hard to create, shape, and protect their slice of the world. In doing so, methods for protecting these slices have changed throughout time as property, dangers, and technology has changed. Common properties to protect in the current time, are the homes and industrial buildings. Cameras and smoke detectors are some of the technologies used now to ensure these environments are kept safe from the dangers that they protect against.

There are a few issues that modern-day safety and security technology present. One such issue is that the systems tend to be limited in the area that they protect. A basic security camera, for example only has a limited point of view. Cameras with the ability to change their point of view can solve this issue but tend to cost more. Another way to resolve the issue is to place more cameras around the environment. Unfortunately, this method also can cost a significant amount.

Current security and safety systems commonly warn people of an issue as its happening. A smoke detector for example, alerts people of a fire when something has already caught on fire. By this time, the home or industry may already be too unsafe for a person to retreat from.

Security robots only recently have been rising in technological advancements. Some of these robots already happen to exist in largely populated environments. They tend to focus heavily on ensuring the security of the people around them. Unfortunately, these robots are not very common or used in homes or small industries due to their high costs. Finally, the robots focus heavily on keeping people safe in terms of security, but they do not focus on the potential safety concerns different environments may present.

II. MATERIALS AND METHODS

The development of the SecuriBot was started in order to provide home and industry owners with a low-cost autonomous sentinel robot. The main difference between the SecuriBot and current security robots is that the SecuriBot also provides safety to people within environments. Being equipped with cameras and sensors, the robot can scan its environment using sight, sound, and temperature detection.

Equipping these sensors and cameras on an autonomous moving platform allows the robot to be a suitable replacement to current safety and security technologies. Using the abilities of sight, sound, and temperature detection, the robot has the potential to find and warn people of dangers before they happen. For example, if an electronic device was starting to heat up, the robot would detect the temperature of the device was rising to dangerous levels and may soon cause a fire. When constructed, the robot is comprised of a sensor, mobility, structure, and power system.

A. Sensor

Currently, the SecuriBot is equipped with two cameras. The D435 Intel Real Sense Camera provides the robot with the ability to have a sense of depth. With depth recognition, the robot can learn about its environment to be able to do something as simple as object avoidance or something as complicated as object recognition. An Adafruit AMG8833 IR Thermal Camera is equipped on to the robot to provide the robot with the ability to detect thermal-based environmental changes.

The SecuriBot also contains two sensors. To provide the robot with environmental temperature detection, the DHT22 (AM2303) temperature and humidity sensor have been placed on the robot. The SecuriBot equipped with this sensor
allows it to inform a person of the temperature and humidity in the environment and warn them of potential temperature related dangers. Finally, a SparkFun SEN-12642 ROHS Sound Detector has been equipped onto the robot to give it the ability to hear. This gives the robot with the potential to recognize sounds that may cause danger to the environment or the people within it. Each of the sensors and the thermal camera is controlled using an Arduino UNO Board.

**Figure [1]: Sensor and Camera Diagram**

### B. Mobility

The mobility system is constructed of four Phidgets DCM4003_0 high-torque motors incorporating four Nexus robot 14094 100mm Mecanum wheels selected for optimal structural mobility. Two Cytron MDD10A dual-motor drivers are used with an Arduino UNO and a Sparkfun DEV-09947 USB Host Shield for wireless remote control of the Securibot.

### C. Structure

The Securibot’s structure is composed of 80/20 parts 25_5050 (center column), 1012_S T-bar structural supports separating two 80/20 2664 HDPE (high-density polyethylene plastic) pegboard platforms all resting on the 0.9m square plywood actuation base.

**Figure [2]: Securibot completed structure**

### D. Power

Securibot receives power from a 24V battery. The motor controllers are connected directly to the battery whereas the LattePanda is connected to the battery using a step-down transformer. The sensors then individually receive power from the LattePanda. Since the LattePanda could supply up to 5V and 2A, yielding 10W, the step-down transformer maintains the same power by reducing the voltage from 24V down to 5V while increasing the current from 416mA to 2A. The LattePanda is a computer, and it connects to two Arduino UNOs and a D435 Intel RealSense Depth Camera. Both Arduinos are basically a piece of memory. One Arduino UNO connects to a DHT22 Temp/Humidity, a LMV324 Sounds Sensor, and a AMG8833 Thermal Camera. The other Arduino UNO connects to the two motor controllers where the battery connects to, and each motor controllers connects to two motors for a total of four motors. The four motors supply a total of 3A and 24V, and thus each motor supply 750mA.

**Figure [3]: Power Diagram**

### III. Discussion

Currently, the SecuriBot is separated individually into its four main systems, as previously described. In the future the design should be assembled using the structure designed for the SecuriBot. The sensors, D435 Camera, and Mobility system should also be combined using the LattePanda. Acting as the central microcontroller, the LattePanda will have all the programming necessary to make the systems previously described work in unison. In this design, the LattePanda acts as an A.I or the brain of the robot, having the programming necessary to help the robot make decisions based on the information it gathers. As for additional sensors, the SecuriBot’s large structure allows room for many sensors to be added onto the robot in the future. The design of the SecuriBot was carefully thought out to be a platform for future development.

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Design and Fabrication of an 8 Degree of Freedom Mechanism to Address upper Extremity Weakness

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Abstract—This 8 degree of freedom (DOF) robotic arm manipulator (RAM) is designed to help advance the Smart Handle technology. This technology will help to create exo-machines with more intuitive controls. Once fully developed, this technology can help aid people with upper extremity weaknesses. The arm is designed to mimic human arm movement as closely as possible. To do this, 8 actuated DOF are implemented. Majority of the arm components will be 3D printed or manufactured through a CNC process. The shoulder and elbow joints are assembled with a multitude of 3D printed parts. Shoulder and elbow joint movement is facilitated using circular pulleys fitted with bearings into each joint and actuated through the use of Bowden Cables. These Bowden Cables are driven by DC motors. The wrist joint is actuated using small high-torque servo motors. Both the DC and servo motors are controlled using an Arduino microcontroller, motor driver when applicable, and LabVIEW interface.

I INTRODUCTION

The main goal of this arm is to assist the development of the smart handle, which is a novel and intuitive human-machine interface that senses inputs from a user via stress/strain measurements. In order to facilitate further research of the smart handle technology, a robotic arm capable of closely replicating movements of the human upper extremity and allowing interfacing with the smart handle is needed.

To address the problem at hand, which is to be able to fully actuate all 8 DOF for the smart handle inputs, we need to be able to control the motions first. There have been other mobility and strength devices similar to this, but none which integrate the smart handle technology. Due to other cost-limiting factors that other arms have, they are expensive and thus would be difficult to mass produce. The RAM is cost effective, light, and functional, while also including safety features such as physical stops, and real-time motor speed control. After the arm is developed and each DOF can be accurately controlled, the arm will be interfaced with the smart handle prototype. From there, development of the smart handle will continue and will attempt to replace the hard-coded instructions that originated in LabVIEW (National Instruments, Austin, TX).

II DESIGN FEATURES

A. Joint Mechanisms

Looking at the shoulder and elbow joint, there are two circular disks within each joint that are fitted with press-fitted ball bearings to reduce rotational friction. The vertically oriented pulley disks are responsible for flexional and extensional movements of the elbow and shoulder. The disks slide over the custom shafts and are then fixed to said shaft with set screws. The pulley and shaft is then rotated as one piece by Bowden cables. A U-bracket serves as housing for the disks and is bolted over metal links on each side to hold all the pieces together. The horizontally oriented pulley disks on the bottom of the U-brackets are responsible for circumduction of the arm. All pulley disks are controlled with Bowden cables that are inserted through pre-made holes in the U-bracket and then wrapped around the pulleys. The shoulder joint serves as the template for the elbow joint apart from one additional DOF. The shoulder joint at the top of the arm is connected to a DC motor using a shaft that runs through the hollow portion of the T-slot aluminum frame. This generates the abduction and adduction motion for the arm. The wrist joint is comprised of small and lightweight pieces to prevent large moments at the end of the arm. Servo motors are embedded in the aluminum linkages prior to the wrist and are connected to the wrist pieces via servo linkages. The end effector of the wrist is fitted to work with the connections of the smart handle prototype.
B. Bowden Cables

In order to move the shoulder and elbow joints, Bowden Cables are fitted around each pulley and together the two act as an actuated pulley system. The cables are .09375” in diameter and slide inside a Bowden Conduit measuring .111” on the inner diameter and .280” on the outer diameter. The Bowden Conduit gives the cables shape and allows for tensioning of said cables. Without tension the cables could not rotate the disk joints adequately. The cables are fed back along the length of the arm to the 214AM DC motors (AM Equipment, Jefferson, OR), which will be responsible for actuation.

C. Control system

The electrical components of this system consist of 4 motor drivers (214 DC 12V, AM equipment, Jefferson, OR, United States) to be connected with a series of DC motors, servo motors (High-Toque Servo, Pololu, Las Vegas, United States), and an AC/DC power supply. The software used is a combination of LabVIEW and LINX (application development software), utilizing different programming setups to operate servo motors and DC motors. For the DC motors, LabVIEW uses two input buttons to select the direction of an individual motor, which then can be adjusted specifically for a desired RPM. The LabVIEW control of the servo motors allows for selection of angular speed, direction, and angular position.

III DISCUSSION

The normal ranges of motion for a human arm include flexion and extension of the shoulder and elbow, and abduction and adduction of the shoulder and wrist. For the ranges of motion, the RAM is designed to function within the typical ranges of motion for human arms. The RAM can reach above the users head up to nearly 160 degrees as well as flex backwards about 45 degrees. The elbow and wrist also share average human ranges of motion for every DOF. Anti-rotation pegs are implemented as physical stops for the safety of the user and they prevent the RAM from reaching any inhuman position.

This RAM is designed to properly imitate these movements with the advantage of non-backdriveable motors. Non-backdriveable motors allow for safe and controlled movements. Advantages include the prevention of unauthorized use, not allowing someone to manually move the arm without electronics being powered. The RAM can now also hold its position without requiring power at any arbitrary angle.

In order to control the 8 DOF robotic arm, sophisticated control algorithms are needed. Due to the nature of this project where the focus was on mechanical design and construction of the arm, only a basic control interface was designed to validate its functionality.

The arm weighs roughly 4.63 kg, excluding the stand from which the arm is suspended. Also, as mentioned before, similar products have been found to be costly and impractical to mass produce. This design altogether costs roughly $1000 and with further development, could be ready for mass production depending on any changes in material.

IV CONCLUSION

This paper outlines the design for the 8 DOF RAM, a robotic arm that serves as the basis for which smart handle technology can be developed on. With human-like joints, the arm is intended to mimic human anatomy and motion as closely as possible. With each motion being motor controlled, the arm can be programmed to perform predefined motions by utilizing the LabVIEW software. Future improvements include replacing the hard-coded commands in LabVIEW so that motion can be dictated by the user in real time using the smart handle technology. Once fully developed, the RAM along with the smart handle technology is applicable for fully actuated occupational exoskeletons, tele-operation as well as for rehabilitation and assistive devices.
A Device For Assessment of Different Prosthetic Feet By Able-Bodied People

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Abstract— The purpose of this project is to evaluate the ground reaction forces from a prosthetic foot. These forces and moments will be noticed when the examiner loads it during the gait cycle. This includes walking, running, jumping, and stationary stance. The user is to be an able-bodied individual with no lower-limb amputations. The user will be secured to the device by stepping onto the base and strapping their foot and leg to the device. This device is built using parts from a construction stilt which will be used as the examiner’s attachment to the device. Load cells will be mounted between a prosthetic pylon and the foot plate for force measurements. Various kinds of prosthetic feet will be able to be tested by attaching to the pylon at the base of the device. The design of this device is meant to be versatile and modular to allow for different configurations.

I. INTRODUCTION

In the ever changing field of prosthetics and orthotics, technology advancements have been achieved through recent changes in prosthetic devices. The prosthetic foot is the most important component of a lower-limb prosthetic as it forms the basis of an effective amputee gait. Lower-limb amputees have identified many issues with current prosthetic technology including mobility and comfort of long-term use. Improving these devices can be difficult without data analysis to base design improvements on. The goal of this project is to build a device that can measure different ground reaction forces throughout the prosthetic and use this data to improve future technology within this industry.

Measurements of forces and moments in lower-limb prosthetics began in the 1980s with strain gauges glued to the pylon and then progressed to one-of-a-kind dedicated systems designed specifically for O&P studies in the 1990s [1]. Load cells were eventually adopted and incorporated into studies of prosthetics in the 2000’s. These studies were done on individuals with lower-limb amputations. The load cells would measure the forces at the base of the user’s socket.

Force sensors for lower-limb prosthetics have been used in many applications for studying the reactions of these devices. There are many similar devices such as the device built for this project. However, this device uses testing methods that differ from others by using non-amputee individuals to examine different prosthetic feet.

One difficulty that was present for the initial research and design ideas was finding the right force sensor. Measuring the forces from the device is the single most important concept of this device. There were many different ideas thought of including strain gauges, load cells, and accelerometers. The sensor which best fit this design was a single-axis load cell. Each device would need at least four in order to measure the forces in three dimensions. This option was also cheaper than a single three-dimensional load cell of a price almost ten times higher.

II. METHODS

A model of the device can be seen in figure 1. The overall design of this device is meant to accomplish certain requirements made by the client. The core requirements for this device are the ability to attach the device to an individual for examination, force measurement, and a user interface to visualize and interpret data.

The core structure of the device is built around a construction stilt. The stilt is how the device’s examiner will mount to the device and be able to walk and move around. The parts of the construction stilt that are used include: foot plate, upper strut tube, tube clamp, upper leg support, straps, and hardware. This part of the design can also be seen in figure 1; the stilt is shown as the top half of the device. The base of the construction stilt (foot plate) will be secured to a 304 stainless steel plate which will have mounting holes for attachment. Under the steel base plate there will be four load cells for data acquisition. The load cell will have a steel adapter plate underneath to attach a prosthetic adapter to. The rest of the device include the pylon tube and prosthetic foot which can be seen in many different prosthetic applications. A list of parts for the device can be seen in table 1.

The main purpose of this device is to measure ground reaction forces, and moments experienced by the user. Each pair of these devices will include four tension/compression load cells. The load cells will be used to measure the forces and the moments on the leg socket in three dimensions. The best way to measure these forces is to use a single, three
dimensional load cell. However, for this application, 3-axis load cells are too costly. It is possible to achieve three dimensional reaction forces by using four single-axis load cells in a square configuration which can be seen in figure 2.

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Part Description</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amazon</td>
<td>Load Cell</td>
<td>DYMH-103</td>
</tr>
<tr>
<td>Amazon</td>
<td>Drywall Stilt</td>
<td>T&amp;HI-B01GP04SSQ</td>
</tr>
<tr>
<td>MidwestSteelsupply</td>
<td>Base Plate</td>
<td>304 stainless steel</td>
</tr>
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<td>MidwestSteelsupply</td>
<td>Adapter Plate</td>
<td>A36 steel</td>
</tr>
<tr>
<td>Otto Bock</td>
<td>Tube Clamp Adapter</td>
<td>4R91</td>
</tr>
<tr>
<td>Otto Bock</td>
<td>Male Socket Adapter</td>
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<tr>
<td>Otto Bock</td>
<td>Female Socket Adapter</td>
<td>4R37</td>
</tr>
<tr>
<td>National Instruments</td>
<td>Multifunction I/O Device</td>
<td>USB-6009</td>
</tr>
</tbody>
</table>

*Table 1. Device Components*

![Fig. 2. Load cell configuration from one device](image)

III. RESULTS

Using four load cells allows for a wider base to be able to pinpoint the force locations during testing. Each load cell measures forces of tension or compression on a single axis. While the device is loaded, each load cell will measure forces of different magnitudes depending on the user’s movements. The average of the four force readings can be found and the force location on a plane can be located.

The measured data from the load cells will be sent to a National Instruments I/O device. This device transmits the data to a LabVIEW interface where everything can be visualized by the user. This interface will show the information from both devices. Some of this information will be force location, force magnitudes, moments, etc. An example of the force location can be seen in figure 4(a) and 4(b).

![Fig. 3. LabVIEW program block diagram](image)

IV. CONCLUSION

This device will be used for the assessment of different prosthetic feet by various examiners. The data recorded will be used for educational purposes and studies to help improve prosthetic and orthotic parts in the future. This design is simple and easy to use while being relatively inexpensive. The ability for able-bodied people to study the effects of different prosthetic feet when in motion give a different yet positive perspective of what it is like to walk with prosthetic feet.

ACKNOWLEDGMENT

This project was done with the help and support of our client Dr. Hamid Bateni with the school of Allied Health and Communicative Disorders, and Dr. Ting Xia with the department of Mechanical Engineering.

REFERENCES


Abstract: The task of this project is designing a suitable fixture for the Split-Hopkinson bar device in NIU’s lab. The fixture is used to mount the air bearing that is used to support the incident bar and transmit bar. The function of the fixture is not only to mount the air bearing, but also to control the Y-direction and Z-direction displacement of the air bearing. At present, the test device with high strain rate deformation, which is more commonly used internationally, is the Hopkinson pressure bar device. The reason why the Hopkinson pressure bar device is more common is that the Hopkinson pressure bar device has many obvious advantages, such as: simple principle, low cost, high accuracy, can measure a variety of mechanical properties, and can simulate high strain rate scenarios. Wait. The Materials Laboratory at Northern Illinois University has a Hopkinson prototype that can only perform high-strain compression experiments that produce rough signals.

i. Introduction

This project is an improved design; the Split-Hopkinson bar apparatus exists many years in EB143 Lab in NIU. It has been redesigned and improved by many classmates. Now, the high strain rate compression experiment was successful, we committed to finishing the high strain rate tensile experiment. For getting the faster impact speed, the project used half inch bar rather than 1 inch and air bearing which can produce less friction than linear bearing. The air bearing is aerostatic, so the high-pressure air is provided by air pump. Figure 1 shows the model of air bearing.

![Figure 1: Model of air bearing](image)

ii. Methods and Materials

The method to control the Z-displacement is using four screws whose unthread parts are mounted in four ball bearing, in this way, when rotating the screws, the screws will go up linearly, just like jack. The method to control the
Y-displacement is using four slots, the air bearing can be moved slightly in Y-direction, but it is enough. The materials of this fixture are cast iron and steel. The two plates are made of cast irons, others are made of steel.

iii. Results

Due to in the situation, the result of the project becomes the simulate model and stress and deformation analysis. Therefore, figure 2 shows the model of the fixture and figure 3 displays the deformation of the fixture when the load and boundary condition are set on the fixture.

![Figure 2: The 3D model of fixture](image1)

![Figure 3: The result of deformation analysis in ANSYS](image2)

iv. Discussion

The cost of this fixture is huge. It takes 1000 dollars. The assemble procedure is complicated, it needs sleeve bearing and skills of assembler. The ball bearings are not sealed, so they are need be lubricated on time.

v. Conclusions

In SolidWorks, the extra freedoms of motion are restricted. Then we can simulate the motion of screws, bearings, and bolts. It shows that the fixture can mount the air bearing suitably and accurately. In ANSYS, the contact condition and boundary condition are set, then deformation of fixture is calculated out. The maximum deformation is $2.3 \times 10^{-6}$ millimeters. The value is so small that shows the fixture is adamant and reliable. That mostly is because that the air bearing is an aerostatic air bearing; the high-pressure air loads a hooked force, the resultant equals zero. The fixture just needs support the gravity of the air bearing. After the materials arriving, we will machine the plates and assemble the fixture for the device.

vi. Acknowledgements

I would like to express my gratitude to Dr. Gau, Matthew Kleszynski and Dian Li. You help me so much in the process. I also thank NIU for providing enhanced research resources and enrichment meetings. Thanks, all of you.
3D FLUID FLOW SIMULATION FOR EDUCATION

Team 73

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Abstract— This project will provide the user an interactive experience with a 3-D fluid simulation in virtual reality (VR). The goal of the project is to make learning fluid mechanics an interesting experience and that teachers will be able to use it in their classrooms or encourage k12 students to choose Science Engineering Technology and Mathematics field. The team will use the game engine Unity to complete this interactive experience with fluid flow. Two applications have been created. Firstly, biological flow simulation data from Lattice Boltzmann method (LBM) was utilized to make an animation with cancer cells moving with a stream of red blood cells. The cells were generated in Paraview using LBM data to create these Unity object models and their placements in the bloodstream. Second, the team also utilized the Smooth Particle Hydrodynamics (SPH) from an open source code to create an interactive fluid flow simulation within Unity by Leonardo Montes. The user can use a mouse to move a control object to interact with fluid particles in Unity. The user will also be able to move the SPH particles with the arrow keys. In addition, the user can examine detailed flow physics such as how each particle of the fluid interacts with each other. The interactive program was implemented with C# script in Unity to make the simulation as real world as possible.

I. INTRODUCTION

Fluid Mechanics is the basis for the entire project and is essential in mechanical engineering as well as other engineering disciplines that deal with physical systems. Its application can be found from irrigation canals to toy water guns. Many of today's greatest technological advancements would not be possible without fluid mechanics. Understanding fluid mechanics has been enhanced in modern times using computer systems. Furthermore, virtual reality technology combined with fast computational processors is allowing us more than ever to simulate fluid behavior in real-time with an immersed environment.

The use of a game system and a virtual reality headset will give a broader perspective on what the project could be to peak interest in STEM fields by allowing children to use the simulation. The link between a game and learning is a powerful tool because it helps engage students with the material they are learning. Unity was chosen for this very purpose so that students can possibly learn a very difficult subject. A game will get more attention and interaction from a student than the traditional form of a classroom lecture and textbook. The visualization via the virtual reality also enforces what amazing experience the STEM field can create and helps give different perspectives on the flow of fluids and how individual particles interact.

II. DESIGN FEATURES

A. SPH Particle movement with arrow keys

The team was able to make a selected particle in the simulation to move according to a exerted force. For example, in order to move a particle in the direction of the z-axis, there would have to be a force vector with just a force vector with a z-component. The implementation is done using the Vector3 function in Unity. The engineering group decided on a base acceleration constant of 9.81 to imitate a similar force when gravity is acting on the particles when it is free falling. Next, the acceleration vector must be multiplied by the density and a scaling factor set by the user for the particles to be pushed off each other. The density allows this particles to actually have an interactive force between the particles and the scaling factor on the force vector allows the user to get different interactions; such as moving the particle by a small amount or a large amount when pressing the arrow keys. Afterwards, this force will be applied to the particles game object array through the forcephysics vector. A simple if statement was used to determine if users press down the arrow keys so that a designated force is added to the particle to move it.

B. Object interactions with mouse in SPH simulation

The team used the SPH algorithm to create the interactive flow simulation. In Unity, a control object was introduced with a tag SPH Collider, as shown below.

Figure 1: Apply a tag to the control object in Unity

The simulation detects any collisions that happen between any object with the SPH Collider tag and any SPH particles. Through the collider tag, any object that does not belong to SPH particles can interact with each other and with SPH particles. With the same tag, any Unity object that is made outside of the simulation becomes a part of the simulation. Therefore, an item like a sphere created outside SPH particle group was made to collide with the SPH particles. The item has a script where the user can control and drag it around the world with the use of a mouse. This can spark interest within.
students because they do not simply look at the simulation animation but they can interact with simulation as well.

C. Simulation Video with red blood cells and cancer cells

Additionally, the team constructed a simulation that includes moving cells within a flow. Using cell data generated by Paraview, a 3D Data Visualization software, we were able to convert these cells into Unity objects, i.e. Each of the cells was converted to a .obj file which stored the coordinates for the cell. Taking time sequential data for the cells and essentially playing them one after another the team was able to see how the cells moved in real time.

III. RESULTS

In Fig. 2, the team mimicked a simulation done by Dr. Tan and his research group. This was done for an educational purpose in order to show precollege students how cancer cells moving in a microfluidic filter. This can also be linked with a virtual reality headset to see how blood cells move in a 3D environment.

![Figure 2: Visualization of simulation results of cancer cells (green) moving with red blood cells in a microfluidic channel with cylindrical posts.](image)

The team also created a working fluid simulation that the user can interact with using a mouse, as shown in Fig. 3, and arrow keys, as shown in Fig. 4. The gray sphere is not part of the SPH particles. We successfully collided the gray sphere with the SPH particles (blue). Fig. 3 shows that the gray sphere can impact the SPH particles and break the SPH particle cluster apart.

![Figure 3: A gray sphere controled by mouse impacted SPH paticles and break the SPH particles apart.](image)

Fig. 4 showed another example where a force vector was added to move the sphere along a specified direction. The particle was moved up in the Y-axis (In Unity Y-axis is your vertical axis in 3-D). This adds another layer of interactivity for the user to be able to do with the SPH simulation.

![Figure 4: Arrow keys were used to control force magnitude exerted on a target sphere colliding with SPH particles.](image)

IV. Conclusion

The main objective of this project is to inspire children to go into the STEM field by showing them a visualization of complicated flow simulation. Unity provided the versatility needed to complete both goals of the project. Unity helped make an interactive experience that any student will find engaging. The use of SPH method helped create various real time fluid simulations. Our team was able to make the user move a sphere outside the simulation and have it interact with SPH particles using the mouse. Unity also helped with movements with the SPH particles themselves with the use of the arrow keys. These interactions help steer away from the regular classroom and book format to a more interactive experience in learning fluid mechanics. Unity and its compatibility with virtual reality also gave another way to visualize data such as shown in Fig. 2. The virtual reality headset offers different perspectives of the blood flow, giving the user a different range of visualization angles and different locations in an immersed environment. Unity showed that it was the best way to create a more immersive learning experience with fluid mechanics.

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We would like to thank Dr. Tan for guiding us throughout this project. We would also like to thank out Senior Design teaching assistant Sandhya Chapagain, as well as the Computer Science students in the DDilab for helping us understand Unity.

REFERENCES

“Senior Design is the pinnacle learning experience of an engineering student’s undergraduate education. It is a year-long process during which principles and theories gain substantive form and relevance to societal needs. Students learn and apply the principles of design; the complex interplay among engineering solutions and societal, environmental, economic, and ethical considerations; the language of industry; and the power of engineering to catalyze new solutions to entrenched problems.”

- Donald Peterson, Ph.D., Dean