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 protype was designed using modern robotic mechanism 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.

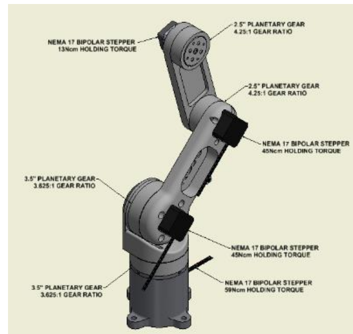

Figure 1: Detailed View of Robotic Arm (Inventor)

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.

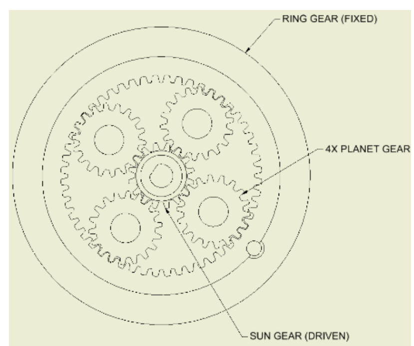

Figure 2: Detailed View of Planetary Gearbox (Inventor)

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.

$$Nr = Ns + 2Np \quad \textbf{(1)}$$

Nr=number of teeth of ring gear, Ns = number of teeth of the sun gear, and Np= number of teeth of the planetary gears.

2.5" Gearbox (Number of Teeth per Component)	
RING GEAR	52
SUN GEAR	16
PLANET GEAR	18
3.5" Gearbox (Number of Teeth per Component)	
RING GEAR	84
SUN GEAR	32
PLANET GEAR	26

Table 1: Gear Teeth Table

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]

$$\text{Gear Ratio} = 1 + (Nr/Ns) \quad \textbf{(2)}$$

Nr=number of teeth of Ring Gear and Ns = 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.

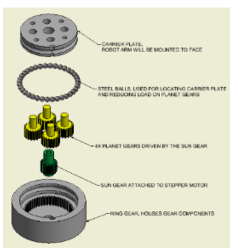

Figure 3: Exploded View of Planetary Gearbox (Inventor)

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.

$$\text{Voltage} = \text{Resistance X Current (Ohm's Law)} \quad \textbf{(3)}$$

Motor	Qty	Amperes	Ohms	Voltage
STP-MTRL-14034	1	0.8	7.66	6.128
STP-MTR-17040	2	1.7	1.6	2.72
STP-MTR-17048	1	2	1.4	2.8
Total Voltage				14.368

Table 2: Stepper Motor Voltage Requirements

The Arduino is controlled using Arduino's programming language called processing, which is a C-based language. The Arduino code was configured to run with a desktop application created through Python. The desktop application allows users to manually move individual robot axis. The limits of the robotic arm are controlled using the desktop application. The Arduino and Python code are designed to be expandable for more individualized projects. The software for both programs is free to the general public and open sourced.

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.

Item	Cost	Item	Cost
Arduino Mega	38.5	Arduino Uno	23
Terminal Block	17.9	CNC Shield	7.92
DM542T	38.99	A4988	8.99
Amazon Basics PLA	22.99	Amazon Basics PLA	22.99
Nema 17 Stepper Motor	23	Nema 17 Stepper Motor	23
Nema 17 Stepper Motor	19	Nema 17 Stepper Motor	19
Nema 17 Stepper Motor	28.5	Nema 17 Stepper Motor	28.5
24V Power Supply	16.99	24V Power Supply	16.99
Alloy Steel balls	7	Alloy Steel balls	7
Total	**395.33**	Total	**226.9**

Table 3: Cost Reduction Table

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

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