A Robotic Arm to Check and Rearrange Books in a Library

Grant Proposal

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Executive Summary

Librarians do not have enough time to help students learn about the library and its resources while maintaining order on the shelves. The process of shelving books and ensuring they stay in the right order (“shelf reading”) can be automated. This can be achieved using a five-degree-of-freedom 3D-printed robotic arm controlled by an Arduino Uno and six servo motors.

Keywords: Barcode Scanner, Library, Robot Arm, Robot Claw

A Robotic Arm to Check and Rearrange Books in a Library

Robotic arms are devices that typically mimic the general anatomy of a human arm and are usually used for grabbing and sorting. Robotic arms can be described in degrees of freedom (Sheikh et al., 2023). In this project, a five degree of freedom robot will be designed. Each degree of freedom is an axis on which the arm can move. In this robot, that includes the first joint (shoulder), second joint (elbow), wrist joint, and claw joint. Robots require different degrees of freedom to perform different tasks.

Each degree of freedom requires at least one servo motor. A servo motor is a motor that can be set to a specific angle and is popular with robotic arms for its precision (Shi et al., 2023). The required torque of each servo motor can be calculated by adding gravitational torque and torque due to angular acceleration (Sheikh et al., 2023). This equation can be written as τ=Fr+mr2, where τ is required torque, m is the combined mass of the joint and book, r is the length of the joint, F is the force applied to the joint, in this case gravity, and α is the angular acceleration. The weight of a heavier-than-average book is approximately 2.4 k, and it was multiplied by three as a factor of safety. (Mepani et al., 2022).

The material used to build the robotic arm requires careful consideration. The majority of robotic arms are made of aluminum, however, due to time and cost restraints, this robotic arm will be 3D printed using a polylactic acid (PLA) filament. This robot is small enough that 3D printed parts will be sufficient for supporting the arm. The main drawback of PLA filament is that it is not food safe, but most libraries do not allow food, so this is unlikely to be an issue. Another benefit of 3D printing is that the robot can easily be made specific to the purposes of this project by nature of 3D printing. PLA is also inexpensive and lightweight.

The final important facet of the robotic arm to be considered is the claw. Two types of gear are used in the design of the claw: a spur gear and an internal gear. Two spur gears spin in the same direction on the same shaft. Each gear controls a different side of the claw. The first part of the claw, the left hook, has a spur gear on the end opposite the hook that interacts with one of the spur gears on the shaft. The right hook has an internal gear on the end opposite the hook that goes around the other gear on the shaft. Because of this configuration, the two gears on the shaft can spin in the same direction while moving the hooks in opposite directions. This reduces the number of servo motors required, decreasing both weight and cost.

The robotic arm can identify books through barcodes on their spines. Two types of barcodes were considered: a universal product code (UPC) (Gallagher et al., 2019) and a two-dimensional barcode (Shi et al., 2020).

Before deciding on a barcode scanner, a camera was considered as a method of recognizing books. A similar device (Zhou et al., 2022) developed in China was able to identify books using a segmentation technique. This solution relied on librarians inputting pictures of the spines of books from many angles (Figure 1) so that they could be identified, so it was determined to not be helpful in saving time for libraries. The librarians would have to spend too much time setting up a database of the books, which is counterproductive.

Figure One. The angles of the books required with the camera solution (Zhou et. Al, 2022)

A universal product code is the barcode found on most items in a typical store (Weinstein et al., 2006). A two-dimensional barcode is something similar to a QR code. This arm uses a UPC camera-based scanner as a UPC is easier to fit on the spine of a book and two-dimensional barcodes are more likely to blur (Shi et al., 2019).

Camera-based barcode scanners have grown in popularity recently (Weinstein et al., 2006), leading to laser-based scanners without plastic cases becoming difficult to find and expensive. While laser-based scanners are more accurate, the difference is negligible in this scenario and any slight inaccuracy is not enough to outweigh the benefits of a significant cost reduction. Additionally, the scanner used for this project is not mirror-based. In mirror-based scanners, a small mirror moves around to direct vision while reducing accuracy and cost. This scanner has a real camera, with the main advantage being durability. The scanner is mounted on the end of the robot, and a mirror-based scanner would quickly become de-calibrated.

Section II: Specific Aims

The goal of this project is to simplify library management by eliminating the need for librarians to shelve and check the order of books in a library. This will be done through a robotic arm with a barcode scanner attached underneath (Bevirt & Brinton, 2002). The arm will be able to identify a book that is out of place or picked to be sorted, remove that book from the shelf (if necessary), and put the book in the proper location.

Specific Aim #1: Create a working robotic arm with a claw capable of grabbing books

Specific Aim #2: Incorporate a barcode reader.

Section III: Project Goals and Methodology

Specific Aim #1

Create a working robotic arm capable of supporting the weight of a book

Justification and Feasibility. Robotic arms are devices that typically mimic the general anatomy of a human arm and are usually used for grabbing and sorting. Robotic arms can be described in degrees of freedom (Sheikh et al., 2023). In this project, a five degree of freedom robot will be designed. Each degree of freedom is an axis that the arm is capable of moving on. In this robot, that includes the first joint (shoulder), second joint (elbow), wrist joint, and claw joint. Robots require different degrees of freedom to perform different tasks.

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The material used to build the robotic arm requires careful consideration. The majority of robotic arms are made of aluminum, however, due to time and cost restraints, this robotic arm will be 3D printed using a polylactic acid (PLA) filament. This robot is not too large, so 3D printed parts will be sufficient for supporting the arm. The main drawback of PLA filament is that it is not food safe, but most libraries don't even allow food, so this is unlikely to be an issue. Another benefit of 3D printing is that the robot can easily be made specific to the purposes of this project by nature of 3D printing. PLA is also inexpensive and lightweight.

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It's also important to test the device. In order to assess the accuracy of the robot, the numbers of true positives, true negatives, false positives, and false negatives will be calculated after sorting a shelf. True positives are books that are moved to the right place, true negatives are left in the right place, false positives are wrongly moved or moved to the wrong spot, and false negatives are incorrectly left in place. Then, the sum of the true positives and negatives will be divided by the total number of books on the trial shelf, yielding an accuracy percentage (Abouhef et al., 2022). Ideally, the accuracy percentage will fall at or above 90%.

Summary of Preliminary Data. Based on volume and mass analysis conducted in SolidWorks (Table 1), the torque can be calculated (Table 2). The torques required for joints one and two were far too high, so in the future, these joints may need to be rendered as shells with infills to support the sides.

Volume, Surface Area, and Center of Mass of All Parts of Robotic Arm

Part	Volume (Cubic mm)	Surface Area (Square mm)	Center of Mass
Base Bottom	1513156.18	179307.52	(0, 39.28, 0)
Base Top	312686.28	70267.5	(0, 5, 0)
Motor Panel (L)	520432.74	70348.91	(-1.1, 88.75, 0)
Motor Panel (R)	520432.74	70348.91	(-1.1, 88.75, 0)
Joint One (L)	583704.9	77242.94	(-2.68, 10, 0)
Joint One (R)	497587.99	65459.78	(.05, 10, -.19)
Joint Two	839599.55	169305.88	(14.29, 60, -.1)
Joint Three (L)	281587.99	42259.78	(1.86, 9.96, 0)
Joint Three (R)	297883.05	41016.83	(-.43, 9.96, 0)
Joint Three Connector	99422.8	21441.37	(0, 10, .4)
Claw Holder	803324.3	104196.32	(-1.32, 57.6, 0)

Table 1. In this table, created in SolidWorks using the appropriate simulations, various aspects of the parts were calculated. These results can be used to find the required torque and may have applications in future calculations.

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Variables Used in Torque Calculations

Joint	m	r	α	τ
One (L)	729.631125	.3	9	593.94121125
One (R)	621.9849875	.3	9	506.747839875
Two	1049.4994375	.2	9	379.7797975
Three (L)	351.9849875	.15	9	72.7469599687
Three (R)	372.3538125	.15	9	76.8716470312

Table 2. In this table, mass data from Figure 1, the length of the parts, and the desired angular acceleration were plugged into the formula for required torque. These results point to a need for decreasing the masses of joints one and two so that the parts require less torque. Once the torque reaches an acceptable level, it can be used to find the ideal servo motor for the part.

Expected Outcomes. Once the robot has been created, it will be able to move based on an Arduino Sketch.

Potential Pitfalls and Alternative Strategies. SolidWorks simulations are limited by the fact that they are simulations. They can't account for things that are subject to human error, like the 3D printing process or cross-threading screws, so problems could still occur.

Specific Aim #2

Incorporate a barcode reader

Justification and Feasibility. The robotic arm can identify books through barcodes on their spines. Two types of barcodes were considered: a universal product code (UPC) (Gallagher et al., 2019) and a two-dimensional barcode (Shi et al., 2020).

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Summary of Preliminary Data. The scanner is still in the process of being connected to the Arduino. The scanner comes with a PS/2 connection, and that connection splits into two at the end. One of those ports was severed so that the individual wires could be plugged into the Arduino without risking permanent damage to the scanner.

Expected Outcomes. The scanner, once properly connected to the Arduino, can be programmed to recognize the alphabetical order of the books that it scans. That information can be used in conjunction with the arm to determine where the books should be moved.

Potential Pitfalls and Alternative Strategies. In the past, a scanner with a USB interface was used in an attempt to connect to the Arduino. The use of a HAT was considered but ultimately deemed too unreliable and fragile to withstand the movement of a robotic arm.

Section III: Resources/Equipment

Arm

- Servo motors (6)
- 3D printed components
    - Base
    - Base lid
    - Left motor panel
    - Right motor panel
    - Left joint one
    - Right joint one
    - Joint one connector
    - Joint two
    - Left joint three
    - Right joint three
    - Joint three connector
    - Claw holder
    - Left hook
    - Right hook
- M3 BHCS (100)
- Ball bearings (20)
- Gear shaft for servos (3)

- M3 brass heat inserts

Scanner and Electronics

- Arduino Uno
- PS/2 interface camera-based barcode scanner
- SD card
- Male/Female crimp-able pins
- Wire splicers (optional)
- Heat shrink

Tools

- 3D printer
- Wire cutter
- Wire crimper
- USB/Arduino connection
- Ball-end drivers
- Soldering iron with conical attachment
- Computer with Arduino IDE installed

Section IV: Ethical Considerations

The main risk of this project is someone getting hit by the claw. To combat this, bumper sensors might be added to the claw hooks. It is, of course, always a bit risky to do electronics projects. There should be no open fluids near the circuitry and nothing should be done without a ground wire attached.

Section V: Timeline

This is a link to a spreadsheet with tabs for a to-do list and a Gantt chart.

Section VII: References

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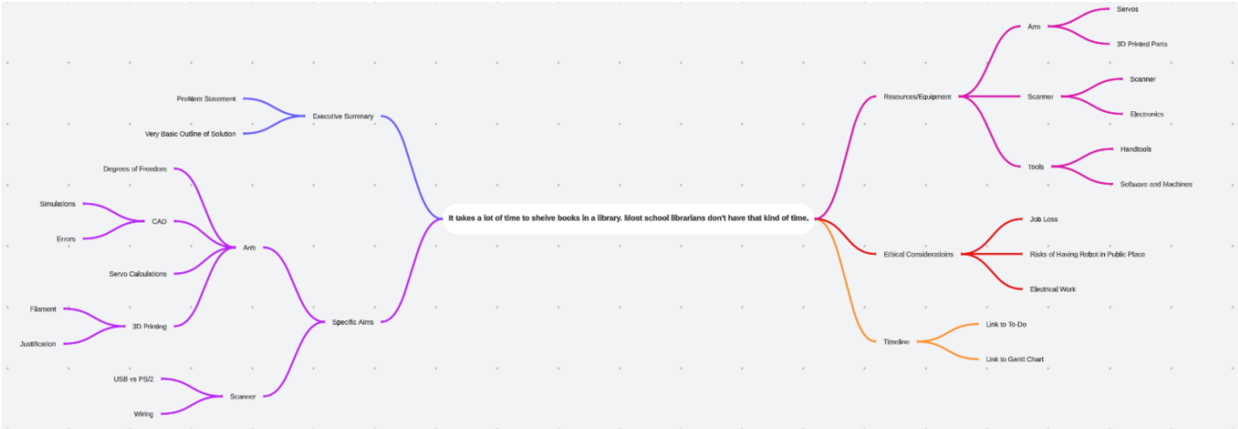

Note: This is a mind map representing this paper. I could not save it as an acceptable file format, so I am putting an image of it at the end. It is not a part of my Grant Proposal Checkpoint One.