EG1004 Introduction to Engineering & Design

Rapid Assembly & Design (RAD)
Final Design Report

Dragon Wing

Scaler Prosthetics LLC.

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Introduction

As older people age, their joints weaken, causing an inconvenience in their lives when reaching for items from a distance or bending down. In a recent poll conducted by the University of Michigan on healthy aging, 70% of older people reported experiencing joint pains due to arthritis; 55% reported the pain to be moderate to severe, and 45% experienced symptoms every day (Wallace, 2022). Along with the high number of arthritis patients, according to the *New York Times*, approximately 12 million older people who are over the age of 65 are in need of equipment to safely assist them in their completion of daily tasks, such as bathing or using the restroom. However, about 5 million of these people do not have access to this equipment due to their high costs (Span, 2021).

The inaccessibility of such safety equipment led to the development of Dragon Wing, an affordable prosthetic limb designed for those in need, including older people and those without limbs, to elevate the convenience of their daily lives and provide them with a great sense of physical security. The Dragon Wing was designed to allow its user to safely reach items at a distance and remove the risk of injury that comes along with such an action. Furthermore, it was designed to alleviate any pain caused by a big reach, regardless of whether it is from a previous injury or an aging body. Along with its functionality, the Dragon Wing was designed to encompass a playful appearance: the embodiment of a dragon wing, with scales, which allows a user to maintain a sense of youthfulness in their daily life. Scaler Prosthetics' mission was to "empower disabled people through enhancing the physical body." Simplicity, functionality, cost, and design were all factors kept in mind in the designing of the Dragon Wing, as it was believed they were key components to the satisfaction of its users. In designing the Dragon Wing, Scaler Prosthetics LLC. was committed to providing the accessibility deserved by all people in need.

An Arduino UNO is a programmable microcontroller with input and output pins, which can be used to complete simple computing tasks (Figure 1). It is programmed using the Arduino Integrated Development Environment.

Figure 1: Arduino UNO microcontroller. (SparkFun, 2023)

A breadboard is a device used for making circuits. It consists of power rails and connection points and allows its users to design temporary circuits (Figure 2).

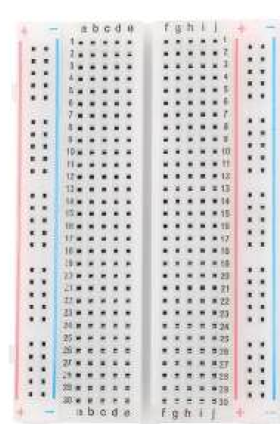

Figure 2: A breadboard. (Vilros, 2023).

A Servo electric motor (Figure 3) is an electric motor that can turn in one of two directions at a time and can be used in a multitude of applications. For example, it can be connected to a breadboard and wired into a circuit, to spin in one direction or the other.

Figure 3: Servo Motor. (EtechRobot, 2023).

A resistor is a device that regulates the flow of electrons. A button is a device that connects together two points of a circuit. It can be used to complete or break circuits, depending on the purpose of its application. A muscle sensor (Figure 4) is a device that can be attached to a body and detects muscle movement. The sensor generates a signal when muscle movements are detected.

Figure 4: Muscle sensor. (SparkFun, 2023).

Autodesk Fusion 360 software is a Computer-Aided Design (CAD) software that can be used to create detailed digital models of physical designs. 3D printers are machines that use melted plastic filament to construct 3D objects designed using CAD software (Figure 5).

Figure 5: 3D Printer. (PLG Global, 2023).

Cura is a software that can be used to ready CAD designs for 3D printing.

Requirements

The hardware aspect of the Dragon Wing was constructed from cost-free recycled cardboard, aluminum foil, and a mechanical hand sourced from Amazon. The electrical components of the device included two Servo electric motors, a breadboard, an Arduino UNO, a muscle sensor, five buttons, five resistors, and 20 electrical connection wires. Additionally, a 3D printer was used for the printing of the device's components.

The software aspect of the Dragon Wing consisted of software for the Arduino board, which was designed to enable the board to communicate with the buttons, muscle sensor, and Servo electric motors. Additionally, Autodesk Fusion 360 was used for the CAD drawings of the device, and Cura was used for the 3D printing of its components.

Procedures

To initialize the development of The Dragon Wing, a brainstorming process occurs where varying ideas surfaced. After the initial brainstorming, a preliminary design was established (Figure 6).

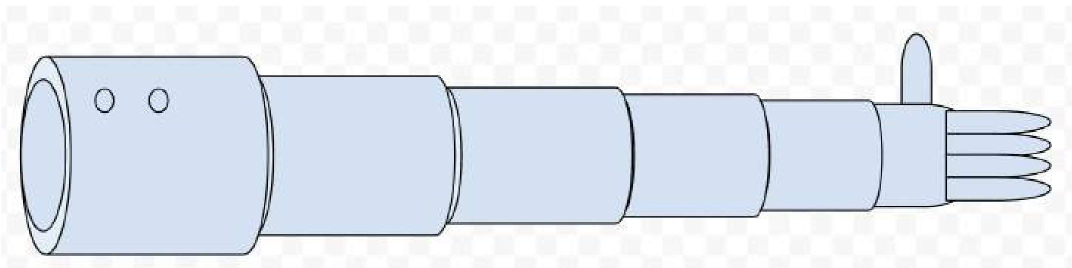

Figure 6: Initial Drawing of Design

After further evaluation, a new design was established in Fusion 360 that incorporated a sliding feature with grooves as well as space for an Arduino board to be placed, as seen in Figure 7.

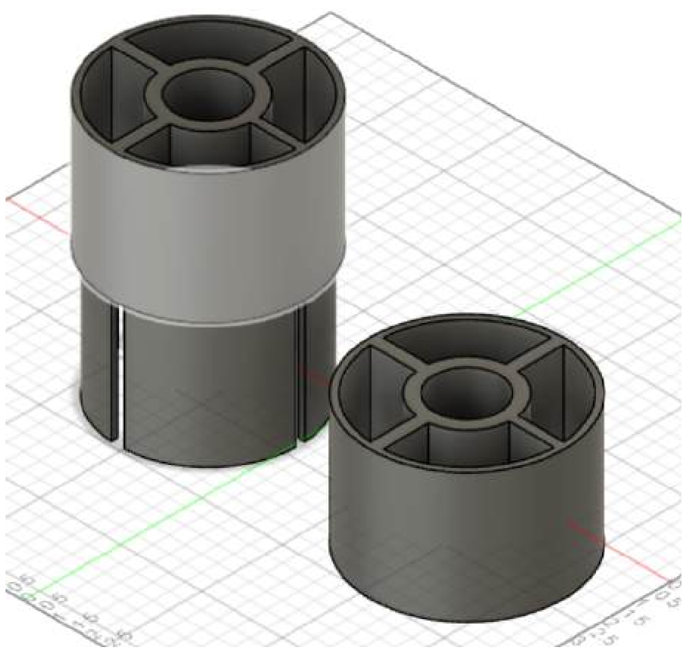

Figure 7: Initial CAD Drawing

The grooved design was printed in the MakerSpace, but due to technical difficulties in the printing process, the design was changed to Figure 8.

Figure 8: Updated CAD Design

The arm was designed to telescope via a pinion on its outer shell, turned by a Servo motor. The pinion was designed to turn on a rack (Figure 9), and cause linear movement of the inner shell. The movement of the inner shell was designed to instigate the extension or retraction of the arm and was to be controlled by two buttons.

Figure 9: Gear Design

This updated method still received further technical difficulties during the printing process, therefore a new material was chosen, cardboard. This process resulted in bending a given recycled cardboard sheet and rolling it into a tube shape. One rolled tube of the cardboard prototype was smaller than the other to allow extension to occur. However, the gear and pinion were printed successfully and glued to the rolled tube (Figure 10).

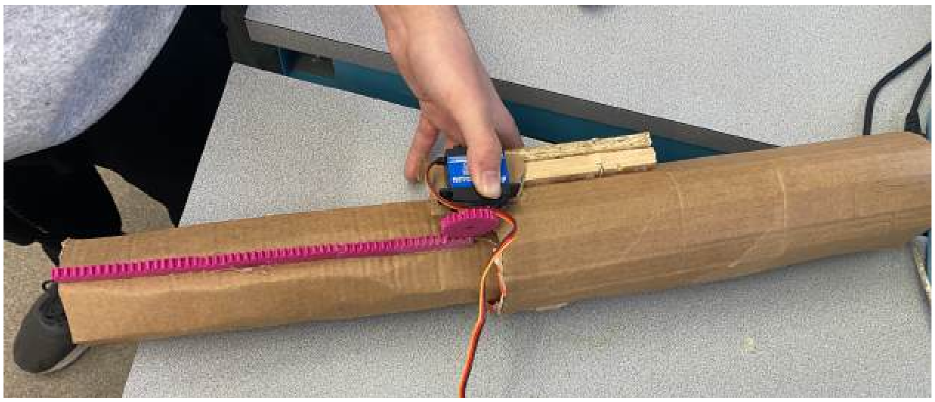

Figure 10: Cardboard Prototype

A wooden mounted piece was applied to the outer, larger cardboard tube to mount a servo motor which provided additional weight to the lightweight cardboard material to maintain contact with the gear and pinion (Figure 11).

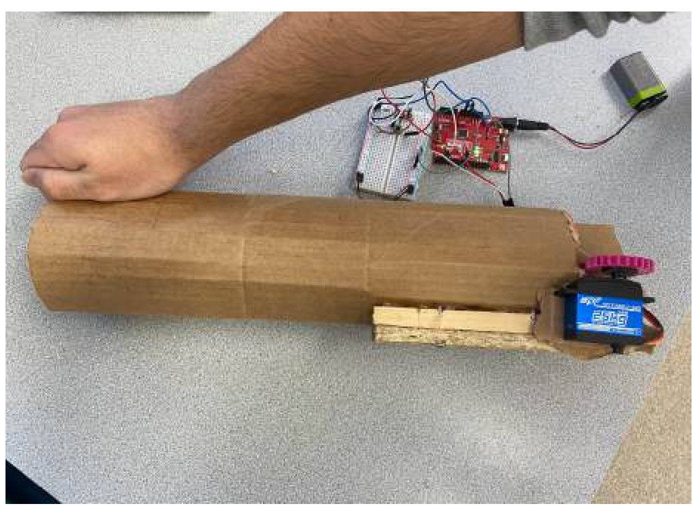

Figure 11: Wooden Mount

An updated CAD model was created that installed an additional hand and the extension gear mechanism (Figure 12).

Figure 12: Updated CAD Model With Hand

A purchased hand was attached to the smaller end of the tube with tape, as well as an additional servo motor to operate the hand (Figure 13).

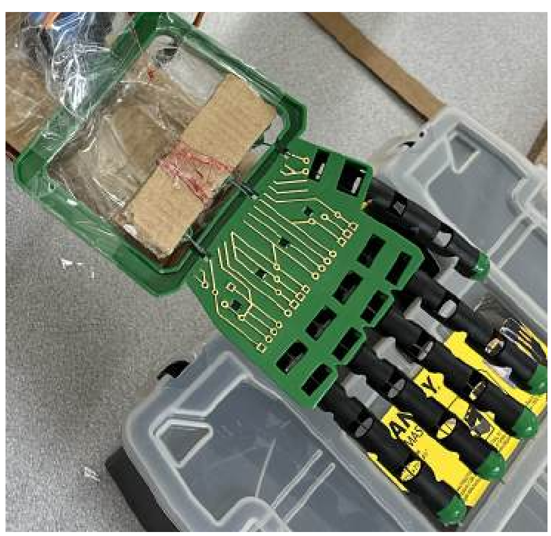

Figure 13: Attached Hand Mechanism

The servo motor was attached to a cardboard piece through a wire that isolated the hand mechanism's strings that were woven through each finger to allow movement of the hand when the motor spins and pulls the wire to a higher tension (Figure 14).

Figure 14: String Hand Mechanism

Two additional compartments to encase the hand mechanism motor as well as the Arduino board, breadboard, and extension motor, along with the addition of aluminum foil to resemble scales were added (Figure 15).

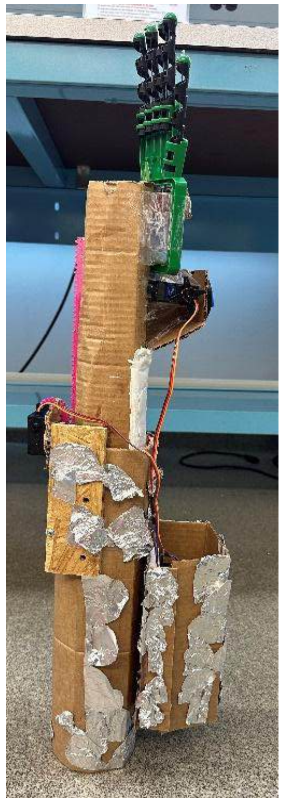

Figure 15: Compartment and Scale Prototype

An updated CAD model was created that highlighted the varying additional compartments (Figure 16).

Figure 16: CAD Model

Code was developed using C++ that utilizes an Arduino UNO board. The initial code output would result in the servo motor spinning left and right based on the corresponding buttons (Figure 17).

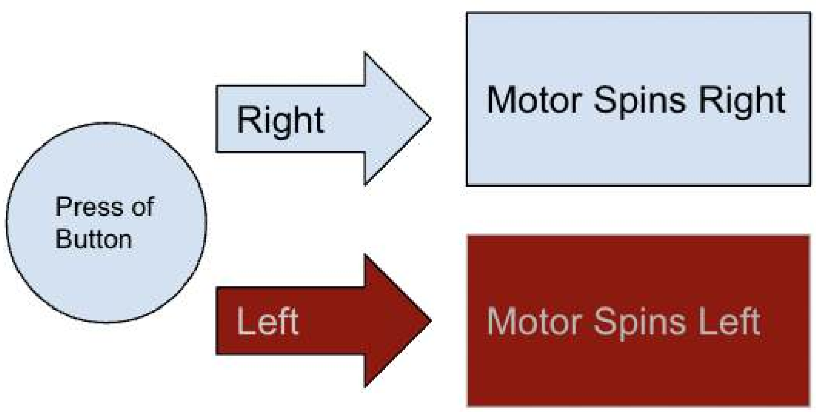

Figure 17: Initial Code Flowchart

The initial breadboard utilized two buttons for the two outputted results of spinning left or right. An initial circuit design was constructed (Figure 18).

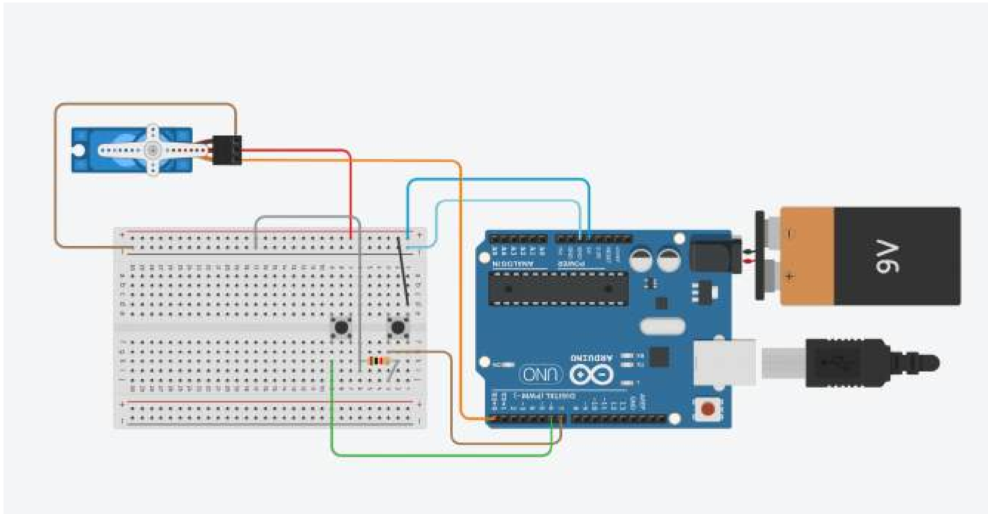

Figure 18: Initial Circuit Design

The updated code read the muscle sensor value to be able to activate the extension, grab, and retract feature with one motion (Figure 19).

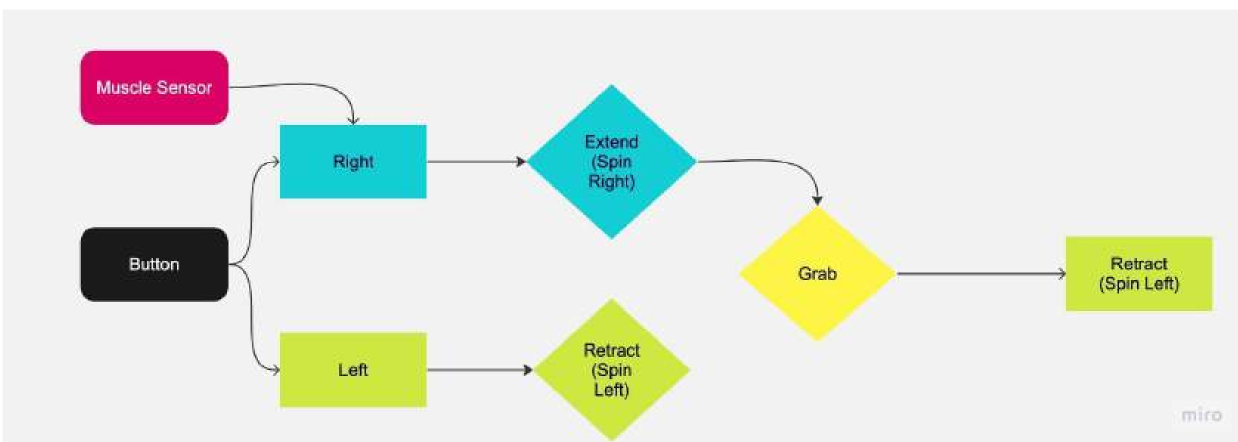

Figure 19: Updated Code Flowchart

The circuitry design added a muscle sensor as well as a switch that could turn the sensor on and off. (Figure 20).

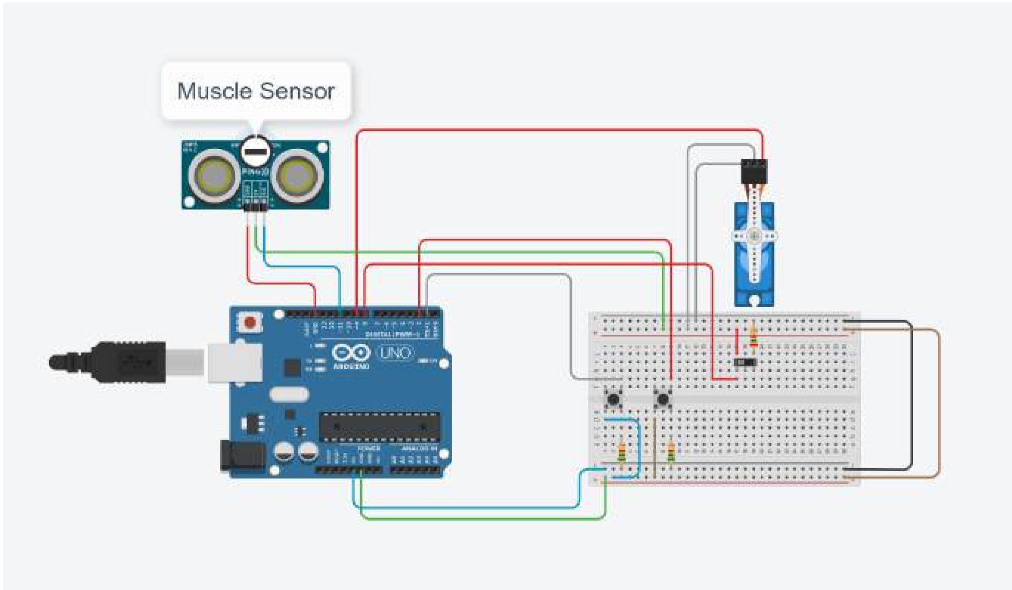

Figure 20: Implemented Muscle Sensor Circuit Diagram

An additional two buttons were added that would spin a separate motor right or left depending on the corresponding button pressed, to grab or release, as well as an updated muscle sensor design that would activate if another button was pressed (Figure 21).

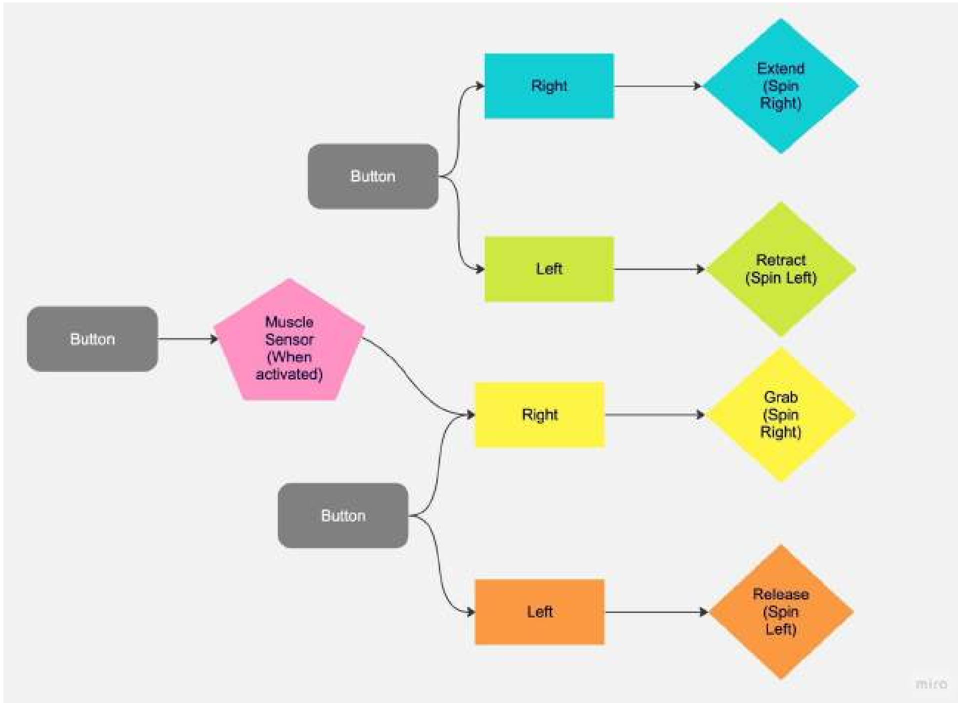

Figure 21: Final Code flowchart

A total of five buttons were attached to the breadboard as well as an additional motor for the hand mechanism. Two buttons for retraction and extension, two buttons to grab and release as well as an additional button in place of the previous switch that would turn the sensor on and off. Essentially, if the sensor was turned on and received a signal (sensed muscle movement), the hand mechanism would be retracted. Once the muscle sensor no longer received a signal, the hand mechanism would be released (Figure 22). The sensor was designed to no longer look for a signal until the additional button was pressed again.

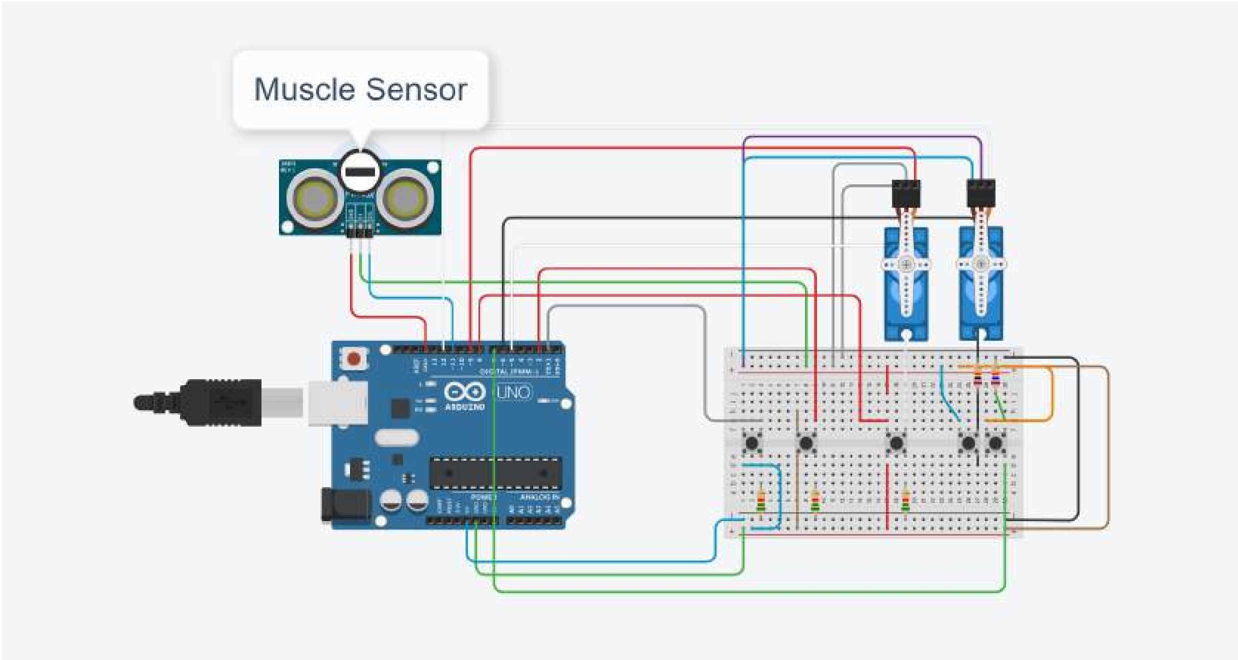

Figure 22: Final Circuit Diagram

The initial global area of the Arduino code consists of defining various objects that are on the arm and breadboard, such as the motor and buttons, to varying ports on the Arduino (Figure 23).

```
#include <Servo.h>
bool contraction = false; //required to allow hand to know whether or not the hand is openned or closed. default to open
Servo myservo;
Servo handservo;
#define servoPin 9
#define LEFT 3
#define RIGHT 2
#define Sensor 13
#define SensorButt 5
#define handPin 12
#define handbuttpull 6
#define handbuttrel 7
//defines all devices used to their respective pins on the arduino board
```

Figure 23: Global Area of Code

Following the global area, the setup area consists of the parts defined in the global area where the input mode is set to have the Arduino read the value implemented (Figure 24).

```
void setup() {
  Serial.begin(9600);
  handservo.attach(12);
  myservo.attach(9);
  pinMode(handbuttrel, INPUT);
  pinMode(handbuttpull, INPUT);
  pinMode(Sensor, INPUT);
  pinMode(LEFT, INPUT);
  pinMode(RIGHT, INPUT);
  //sets all devices to be inputs so the board can read whether or not they are sending in values
}
```

Figure 24: Setup Area of Code

The loop area would communicate with the Arduino to verify if the buttons on the breadboard are pressed, which would determine the direction of the motor rotation (Figure 25).

```
void loop() {

  if (digitalRead(RIGHT) == HIGH) {
    myservo.write(180);
    //if the button to turn right is pressed the servo will turn to the right
  } else if (digitalRead(LEFT) == HIGH) {
    myservo.write(-180);
    //if the button to turn left is pressed the servo will turn to the left
  } else if (digitalRead(handbuttpull) == 1) {
    handservo.write(180);
    delay(100);
    handservo.write(90);
    //if the button to make the hand grab is pressed the servo will turn left to pull
  } else if (digitalRead(handbuttrel) == 1) {
    handservo.write(-180);
    delay(100);
    handservo.write(90);
    //if the button to make the hand release is pressed the servo will turn right to release
```

Figure 25: Loop Area of Code

The loop area would also read if the muscle sensor is outputting data which would turn the feature on or off (Figure 26).

```
else if (digitalRead(SensorButt) == HIGH) {
    if (digitalRead(Sensor) == HIGH and contraction == false) {
      handservo.write(-180);
      delay(3000);
      handservo.write(90);
      contraction = true;
      //if the button that allows the arduino to read the sensor is pressed and the sensor is reading
    }
    else if (contraction == true and digitalRead(Sensor) == LOW) {
      handservo.write(180);
      delay(3000);
      handservo.write(90);
      contraction = false;
      //if the button that allows the arduino to read the sensor is pressed and the sensor is not read
    }
  }

else {
  handservo.write(90);
  myservo.write(90);
  //by default the servo should not move if there is no signal from the devices telling it to turn
```

Figure 26: Loop Area of Code

The initial cost estimate of the Dragon Wing was $4246.83 due to the implementation of a motor controller as well as an electric motor (Table 1).

Table 1: Initial Cost Estimate.

Equipment	Cost Per Unit	Quantity	Cost
Electric Motor	**$6.99**	**1**	**$6.99**
Motor Controller	**$3.00**	**1**	**$3.00**
Receiver	**$14.97**	**1**	**$14.97**
Arduino	**$11.79**	**1**	**$11.79**
Miscellaneous	**$10.08**	—	**$10.08**
Projected Labor	**$50.00**	**84**	**$4,200**
Total			**$4246.83**

Milestone and Final Product Requirements

The requirements for benchmark A consisted of an initial CAD model of the telescoping prosthetic arm in Fusion 360. The locations of the Arduino board and sensors needed to be depicted in the drawings, as well as the arm's extending shafts. Benchmark A also required the submission of a company logo design and the completion of the Preliminary Design Investigation. Finally, Benchmark A required an updated engineering notebook, complete with group meeting accomplishments, next steps, and CAD drawings.

The requirements for Benchmark B consisted of an updated CAD model of the device, an updated engineering notebook, and the approval of the submitted company logo design. Benchmark B also required the construction of a code flowchart, depicting how the Arduino, sensor, and motors were designed to interact with one another. For this requirement, the code for the Arduino needed to be finalized as well. Additionally, Benchmark B required the construction of the device's shafts, and the functionality of the device: the device needed to be assembled, and the code, Servo motors, and buttons needed to be operational. Finally, Benchmark B required the completion of an electrical schematic for the device, depicting the complete circuit with the Arduino, sensor, and motors. For this requirement, the physical circuit also needed to be constructed, in line with the schematic.

The final submission requirements for the project consisted of final CAD models for the device and a fully updated engineering notebook. The final logo also needed to be printed and collected. Finally, the final submission requirements specified that the device needed to be fully functional: the shaft needed to move properly via the Servo motor, as did the hand mechanism. Furthermore, the code for the Arduino needed to work without fail. For extra credit, it was required that the company logo be printed in two colors and that a muscle sensor be employed for control of the hand mechanism.

During the construction and development of the prosthetic arm, the MakerSpace safety training, as well as the 3D printer training, needed to be completed in order to utilize the resources available in MakerSpace. The MakerSpace was used to print the initial design components of the prosthetic arm, in addition to the rack and pinion. The ProtoLab was used to print the final logo, and the Open Lab was utilized to provide necessary device components, such as the Arduino, electrical wires, servo, cardboard, etc. The teaching assistants during Open Lab also provided aid during the process of development by offering solutions to both physical and software-related device issues. Barthi Kakkar and William Iadarola offered assistance in finalizing the code for the Servo rotation, and the muscle sensor signal. Jasper Robertson helped minimize our development time by suggesting cardboard rather than 3D printing for a more malleable product base material.

Results

The requirement for Benchmark A regarding the initial CAD model of the telescoping prosthetic arm was met and marked as a “pass” (Figure 6).

It was determined that the Arduino and sensors would be housed inside the shafts of the arm for a more streamlined design, thus no such depictions were shown in the initial CAD model. The shafts of which the arm was designed to be constructed out of were also designed with CAD software for Benchmark A (Figure 7).

Additionally, the Preliminary Design Investigation was submitted on time, and marked as a "pass." The engineering notebook was successfully updated, and evaluated for the Benchmark A requirements. It was marked as a "pass." Finally, the company logo (Figure 27) was submitted on time, and its requirement was marked as a "pass."

Figure 27: Submitted Company Logo.

Overall, the Benchmark A requirements were all met in time for their early submission, and the Benchmark A form was submitted on February 23, 2023.

The requirements for Benchmark B regarding the logo's approval in Proto Lab, the updated engineering notebook, and updated CAD models (Figure 12) were marked as a "pass," on time for Benchmark B submission.

A side-view image of the CAD model was also generated (Figure 28).

Figure 28: Benchmark B Updated Extended Side View of CAD Model

A front view image of the CAD model was also generated (Figure 29).

Figure 29: Benchmark B Updated Extended Front View of CAD Model

A top-view image of the CAD model was also generated (Figure 30).

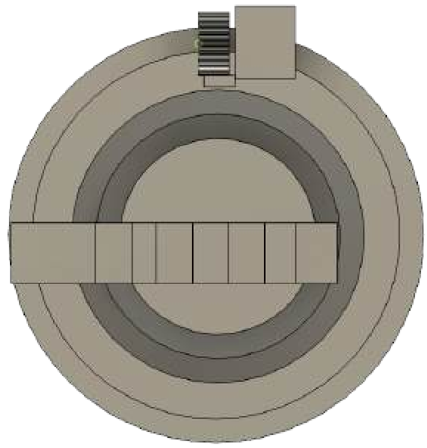

Figure 30: Top View of Updated CAD Model For Benchmark B.

A Most detailed view of the CAD model for the retracted arm was also generated (Figure 31).

Figure 31: Benchmark B Retracted Most Detailed View CAD Model

A side view image of the CAD model for the retracted arm was also generated (Figure 32).

Figure 32: Benchmark B Updated Retracted Side View of CAD Model

A front view image of the CAD model for the retracted arm was also generated (Figure 33).

Figure 33: Benchmark B Updated Retracted Front View of CAD Model

The CAD models for Benchmark B were meant to depict the pieces that had not yet been 3D printed for the telescoping arm's assembly. The taller piece was to extend out of the smaller one to create the extending function of the arm. The circuitry was to be installed inside the pockets of the shafts.

Furthermore, the electrical schematic (Figure 19) was generated using TinkerCAD for the circuit, and its requirement for Benchmark B was marked as a "pass."

The modeled circuit was also constructed physically for installation on the arm (Figure 34), and its requirement for Benchmark B was marked as a "pass."

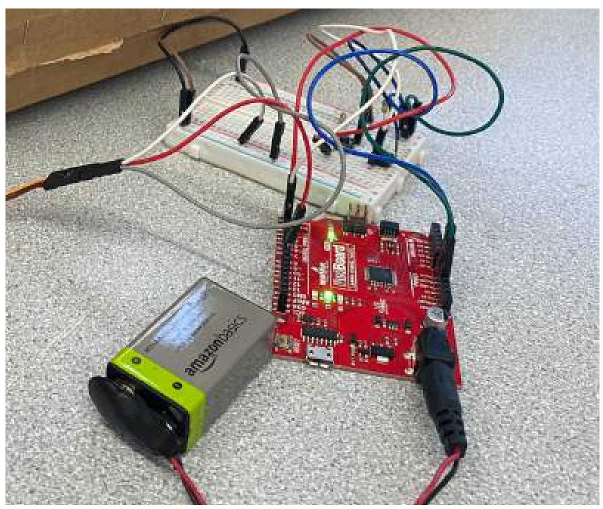

Figure 34: Constructed Circuit For Benchmark B.

The wires extending to the left of the image are those of the Servo electric motor.

A code flowchart was also constructed for the arm's code (Figure 18), and its requirement for Benchmark B was marked as a "pass."

Finally, the shells of the arm were constructed using cardboard, and the device was functional. The arm extended and retracted as it was designed to, and the code worked with the Arduino to control the buttons on the breadboard, which in turn controlled the Servo motor (Figure 35).

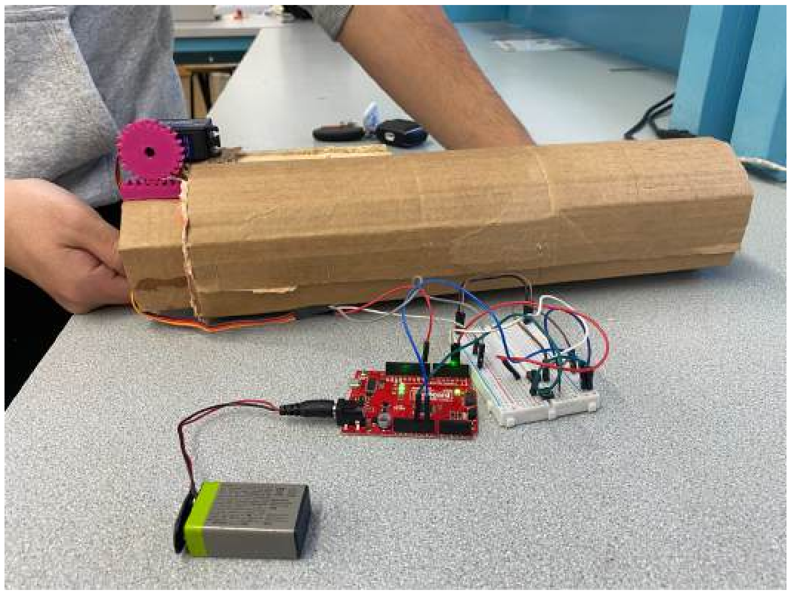

Figure 35: Constructed, Functional Arm For Benchmark B.

These requirements for Benchmark B were also marked as a “pass.” All Benchmark B requirements were met on time, and the Benchmark B submission form was submitted on March 30, 2023.

The cost of the components in the creation of the Dragon Wing totaled to $4333 (Table 2).

Table 2: Dragon Wing Final Cost Estimate

Equipment	**Cost Per Unit ($)**	**Quantity**	**Cost ($)**
Servo	**2**	**2**	**$4.00**
Hand Mechanism	**12.00**	**1**	**$12.00**
Arduino	**12.00**	**1**	**$12.00**
Muscle Sensor	**85.00**	**1**	**$85.00**
Miscellaneous	**20.00**	—	**$20.00**
Projected Labor	**50.00**	**84.00**	**$4,200**
Total			**$4,333.00**

During the design and construction of the Dragon Wing, there were many challenges that arose. One of the largest was regarding the 3D printing of the arm's shells. The 3D printers did not respond well to the long print times and failed on every attempt. Thus, it was decided that the arm shells would be constructed from cardboard.

Additionally, the Arduinos used to control the Servo motor failed numerous times, and required constant attention throughout the semester. The Arduino needed replacing on multiple occasions, which made it difficult at times to complete product development and testing.

Initially, the inner shaft of the arm routinely fell off track and didn't extend properly. This was a problem that required an immense amount of tinkering and was finally solved by using paper towels to create a tight fit between the inner and the outer shaft.

Finally, the hand mechanism was not working as intended, as it would grab before the arm reached its fully extended position. This problem was eventually solved by mounting a separate

Servo motor and buttons for the hand mechanism, which now retracts on demand, using a muscle sensor for ease of use.

Conclusion

The Dragon Wing was successfully designed and constructed to be a fully functioning retractable prosthetic arm. The total cost was $4333. The design process was rigorous, as it involved working with hardware and software components that often revealed design challenges, or resulted in component failures, which in turn required partial device redesign. In development, it was revealed that the original fundamental design piece, the 3D-printed shafts, was not sufficient, and a complete redesign of the arm's shells was required. Furthermore, in testing, it was revealed that the extension of the extending shaft did not function properly and required an extensive process of modification and testing to finally produce a functioning component. The product was on time throughout the semester in terms of meeting benchmark requirements and was always in progress.

For future improvements, it would be beneficial for the arm's shafts to be manufactured in such a way that they fit together with no room in between, as the current design sometimes allows for the inner shaft to move around, which can cause it to fall off the track, and can give a user a sense of instability regarding the device. Additionally, it would be beneficial to add durability features to the device, to make it resilient against contact with water, strong winds, and potential drops/falls, to give the user the confidence needed to rely on the device for daily use. Another component that could be further developed would be to develop an app that utilizes a muscle sensor that could perform all tasks with one muscle input for an additional SOS feature.

Cited Texts:

Span, Paula. "Many Older Adults Lack Even Simple, Helpful Equipment." *The New York Times*, The New York Times, 23 Apr. 2021, https://www.nytimes.com/2021/04/23/health/elderly-medical-equipment.html. Accessed 20 Apr. 2023.

Wallace, Beth. "Arthritis and Joint Pain." *National Poll on Healthy Aging*, 12 Sep. 2022, https://www.healthyagingpoll.org/reports-more/report/arthritis-and-joint-pain. Accessed 20 Apr. 2023.

"Servo Motor 35KG | EtechRobot." *EtechRobot*, https://www.facebook.com/EtechRobot, https://etechrobot.com/product/servo_motor_35kg/. Accessed 20 Apr. 2023.

"Raspberry Pi 400 Hole Breadboard | Vilros.Com | Free Shipping – Vilros.Com." *Vilros.Com*, https://vilros.com/products/breadboard. Accessed 20 Apr. 2023.

"MyoWare Muscle Sensor." https://www.sparkfun.com/products/retired/13723?_ga=2.197928751.1063885814.1681964333-1262359135.1681964333. Accessed 20 Apr. 2023.

"Arduino UNO - R3 SMD." https://www.sparkfun.com/products/11224. Accessed 20 Apr. 2023.

"Ultimaker S3 3D Printer - Plg Global." *Plg Global*, https://www.facebook.com/poligonmuhendislik/, https://www.plgglobal.co.uk/shop/ultimaker-s3-3d-printer. Accessed 20 Apr. 2023.