TANDON SCHOOL OF ENGINEERING

General Engineering Department

Biomedical Device (BMD)

<u>Project Requirements Specifications</u>

The Spring Soldier

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Introduction

The objective of this project is to create a prosthetic limb that functions like a real arm in at least two of three ways. The options for functionalities include a hand, wrist or elbow. The qualification for a working hand required that it could wrap around a shopping bag handle and lift at least one pound of weight. The elbow needed to bend at least 90 degrees to qualify as fully functional. And the wrist requirement was being able to rotate at least 180 degrees. An Arduino program is to be developed to direct the biomedical device, sensors, and any movements that the team decides on implementing. The team needed to conduct research and form an accurate cost estimate, while recording and explaining any choices for physical or technical components. Technical design drawings, as well as schematics for circuit boards, and coding snapshots were also central requirements for this project. The biomedical device needs to be one independent, self-powered, complete device with no loose or hanging components. All outputs should be controlled by sensors and electric inputs, and the final device could not include a breadboard. The final device must be fully autonomous and could not be altered or switched during any part of Benchmarking or Commissioning.

Today, two million individuals suffer from limb loss in the United States, while 200,000 new amputations are performed annually. Worldwide, there are two million amputations performed annually, namely one amputation every 30 seconds. 50 percent of amputations are caused by vascular diseases and diabetes; 45 percent is caused by physical trauma, and 5 percent is due to cancer. Due to the increasing prevalence of a sedentary lifestyle, as well the uncontrolled situation of accidents, the number of amputees produced annually is steadily increasing.

Aside from the inability to perform normal daily activities, amputees suffer from cascades of other physiological, psychological, and social problems. Due to the loss of their limbs, amputees sometimes lack the motivation to engage in physical activities, thereby leading to a deteriorated health condition that arises from long-term inactivity. Moreover, due to their increased dependence on others, discrimination from the public, self-criticism, and other mentally harmful consequences of amputation, amputees are more susceptible to mental health problems such as anxiety, depression, insomnia, and in some cases, suicidal tendencies. Given the prevalence and impact of limb loss, a thorough and accessible solution is imperative for society to create.

Biomedical engineering is the application of biology and engineering to design new and innovative devices to improve healthcare and medical options. Some of the most well-known biomedical devices include artificial organs, prosthetics, wearable devices, and surgical robots. Some current examples of prosthetic limbs include the neuron-controlled arm, developed by Johns Hopkins University, and the prosthetic legs (Figure 1), developed by Hugh Herr at MIT's laboratory.

Figure 1: Dr. Hugh Herr with Prosthetic Legs

These prosthetics implement neural signals from human subjects' brains, and generate movement, while transferring haptic feedback back to the human brain. While expensive, these machines serve as some of the hallmarks for biomedical prosthetics. These devices have saved and improved the lives of countless people around the world, and this project allows for experimentation with constructing a prototype for a working prosthetic device.

Requirements

For this project, a Computer Aided Design (CAD) model was used to represent the construction of the prosthetic arm. Due to the entire team being fully remote throughout the semester, there were no physical components constructed. However, the CAD model served as the group's working prototype, and animations were created to demonstrate the functionality of the different components of the arm. Had the group been working in the actual laboratory, plastic 3D printing material and string would have been used to assemble the prosthetic arm and hook it up to the circuits. In addition to the CAD model and construction materials, the group was also unable to construct the physical circuitry for the prosthetic and needed to model it using online softwares.

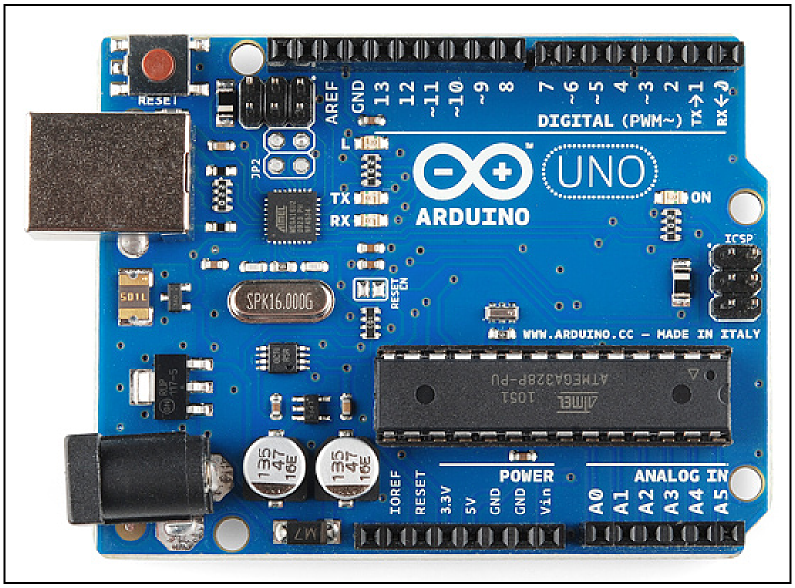


Figure 2: Arduino UNO Microcontroller

This project also required a software element to the prosthesis. Arduino was the programming platform used for the circuits involved in the project. An Arduino Uno microcontroller (Figure 2), as well as a 40-wire Arduino cable pack was used in this project. The circuitry also included a 9-volt battery, a Myoware muscle sensor (Figure 3), and a Servo motor.

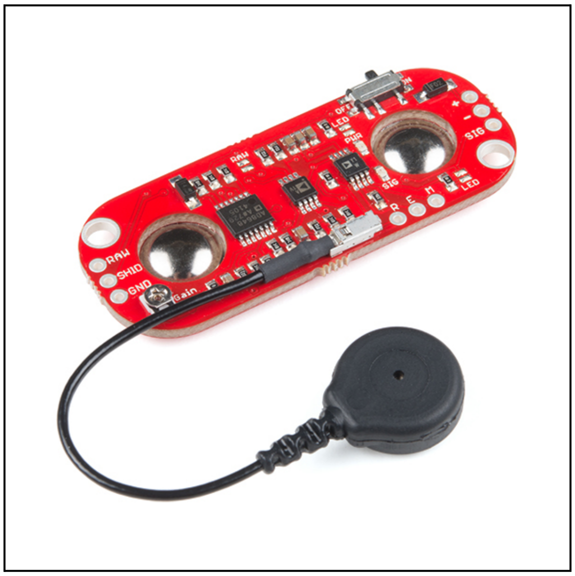


Figure 3: Myoware Muscle Sensor

All these components were modeled in a schematic using an online software program called Fritzing, and later simulated on a separate software program called TinkerCAD.

Procedure

To mimic natural human biomechanics as closely as possible, a thorough research in the biomechanical model of the human hand was conducted. Specifically, the degrees of freedoms of a human hand and joint types were identified and confirmed using existing literature on human anatomy and biomechanics. Through analysis, it was concluded that a revolute joint was needed for the elbow, a universal joint was needed for the wrist, one universal joint and two revolute joints were needed for the thumb, and a total of 2 revolute joints was required for each of the remaining fingers. Further research was done to determine the optimal way to realistically design each individual joint. A revolute joint was created by cutting two holes into each of the individual links connected by the joint. The universal joint was decomposed into two orthogonal revolute joints for maximum fabrication convenience.

In accordance with the aforementioned research, a preliminary design was constructed using TinkerCAD. This initial design (Figure 4) was used to depict how there would be a hinge at the wrist joint and at the elbow joint to simulate a regularly bending arm.

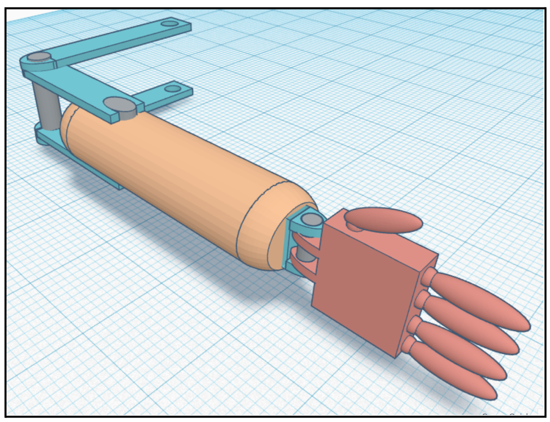


Figure 4: Preliminary Design (TinkerCAD)

This preliminary design also laid out the plans for a hollow connecting point for the user to place his or her residual arm into the upper arm of the prosthetic. A virtual rendering of all mechanical components including fingers, wrist, palm, forearm, and upper arm was later created accordingly, using a CAD modeling software called Autodesk Fusion 360.

On Fusion 360, each individual component was constructed separately. The forearm was modeled first (Figure 5), as a cylindrical and hollow figure with a round connector at the wider end, for the elbow, and a narrower rectangular intrusion, for the wrist to connect to. The wide end was later hollowed out and intruded, allowing for an upper arm to connect.

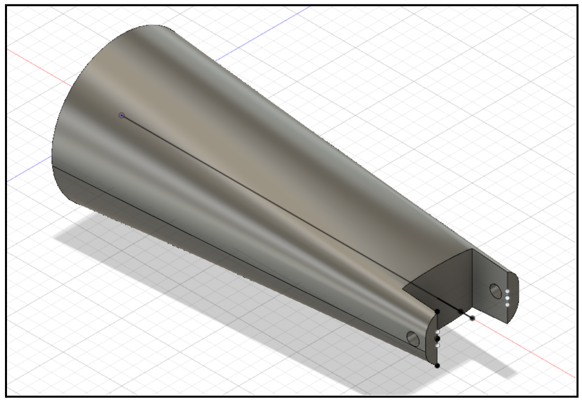
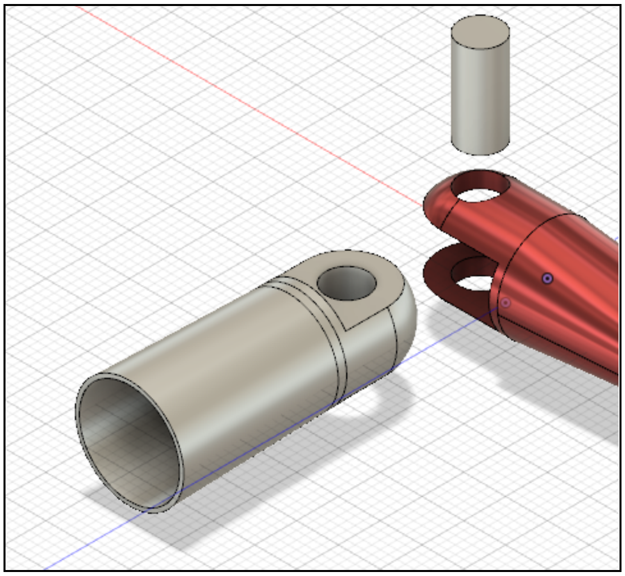


Figure 5: Initial Forearm CAD Model

The upper arm was constructed first as a simple cylinder, and later shortened and hollowed out so that a user can slide his or her amputated arm in and out of the arm with ease. The upper arm and forearm were attached using a cylindrical rotating connector that goes through both components, allowing for a sturdy connection, but also an easily rotating elbow. Figures 6 and 7 show the upper arm and the place where it connects to the forearm in the final CAD.



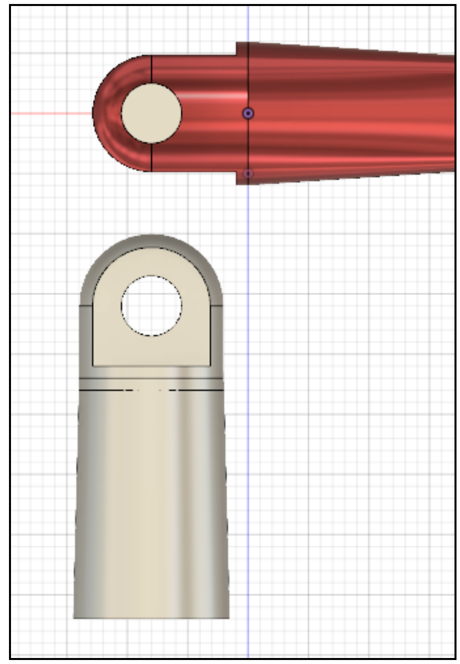


Figure 6: Upper Arm Model (Isometric)

Figure 7: Upper Arm Model (Top)

The hand was the last thing that the group worked on, as the initial plan was just to create a functioning wrist and elbow, excluding the hand. The hand was later worked on for extra credit and paid more attention to in the later parts of the project. A rounded trapezoid shape was used for the palm of the hand, and small ovular shapes were used for the small segments in a hand.

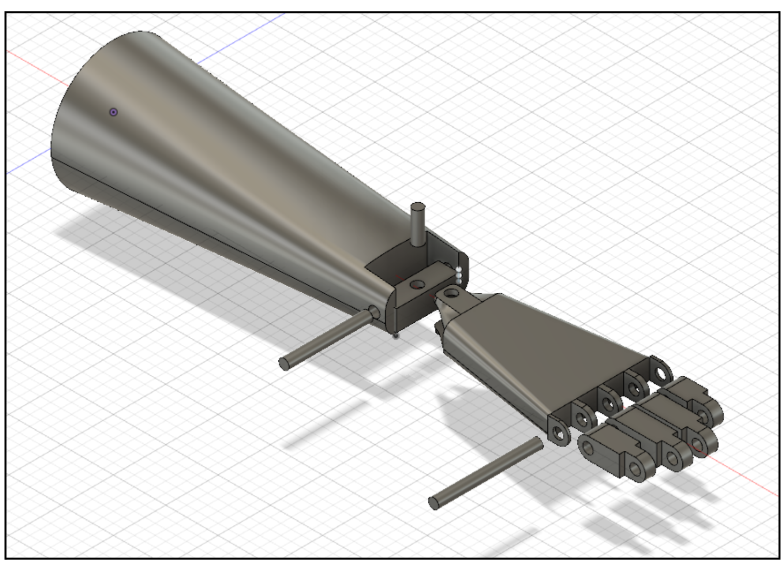


Figure 8: Working Model of Forearm and Hand

The palm was directly connected to the wrist using a universal joint method. Figure 8 shows how the hand was designed to connect to the forearm to form a wrist capable of rotating 180 degrees vertically, and up to 30 degrees left to right. A thumb was created later using both revolute and universal joints (Figure 9).

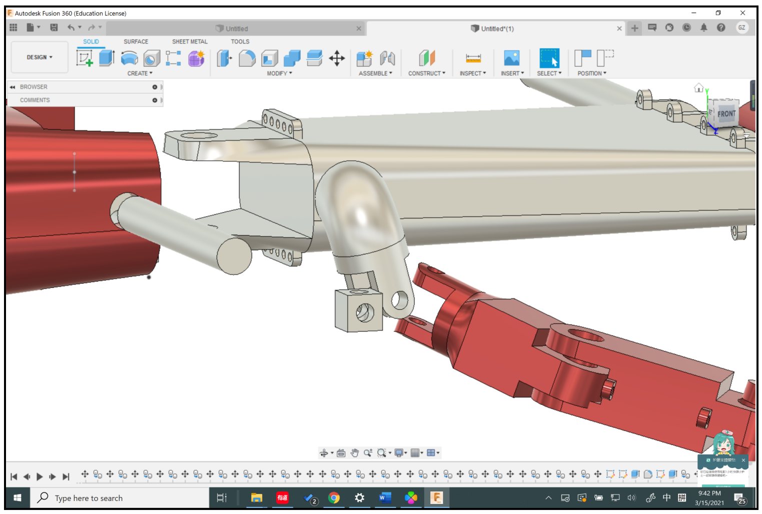


Figure 9: Working Model of Prosthetic Thumb

More segments were added for each finger, and the four fingers, excluding the thumb, were attached to the palm using multiple revolute joints. The forearm was extended slightly and made hollow (Figure 10) to allow the Arduino cables and microcontrollers to be stored inside. Figure 10 also shows the addition of slots on each finger for the Arduino cables to go through, controlling each finger joint separately.

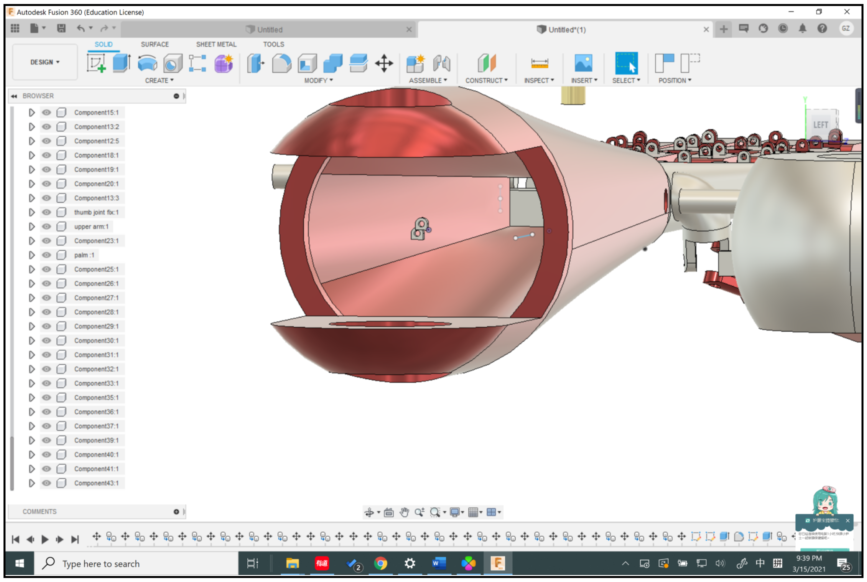


Figure 10: Hollow Inner Forearm

It is also noted that the color of the forearm, as well as the fingers, were changed to red, while the rest of the model was made grey. This was due to the group being inspired by the Metal Gear Solid Bionic Arm. The isometric (Figure 11), front (Figure 12), and top (Figure 13) views of the complete CAD model are shown below.

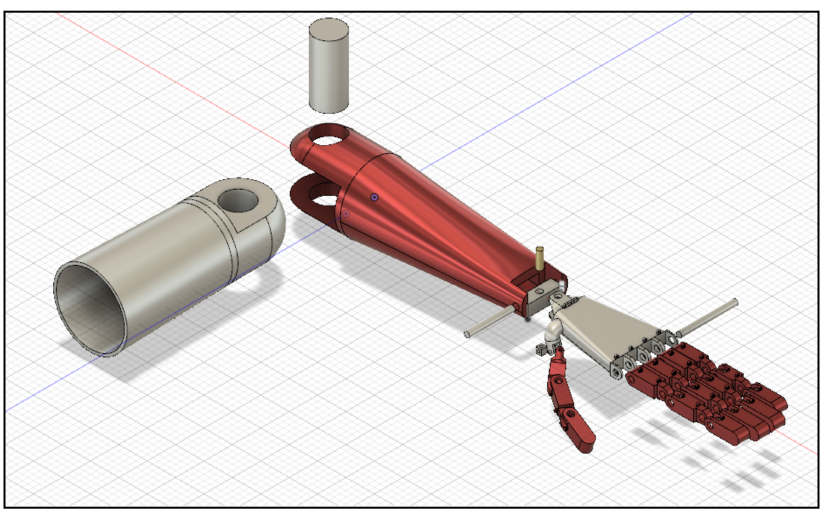


Figure 11: Final CAD Model (Isometric)

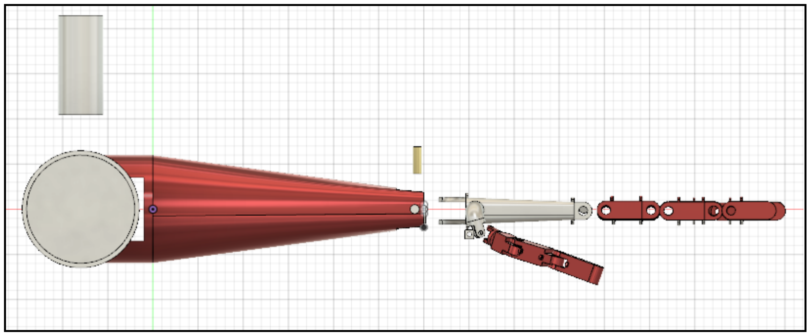


Figure 12: Final CAD Model (Front)

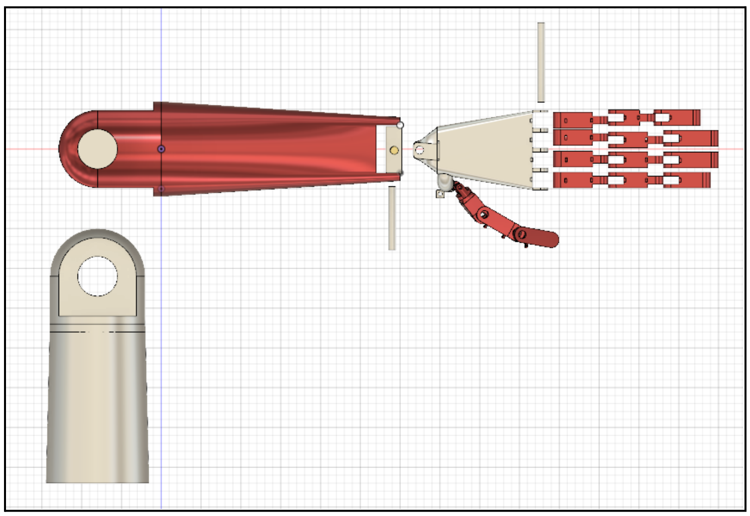


Figure 13: Final CAD Model (Top)

Software setup

For the Arduino portion of this project, the online software, Fritzing, was used to create the schematic of the circuitry using the Myoware muscle sensor (Figure 3). This circuit diagram (Figure 14) depicts the muscle sensor being connected to the Arduino microcontroller, which is powered by a 9-volt battery.

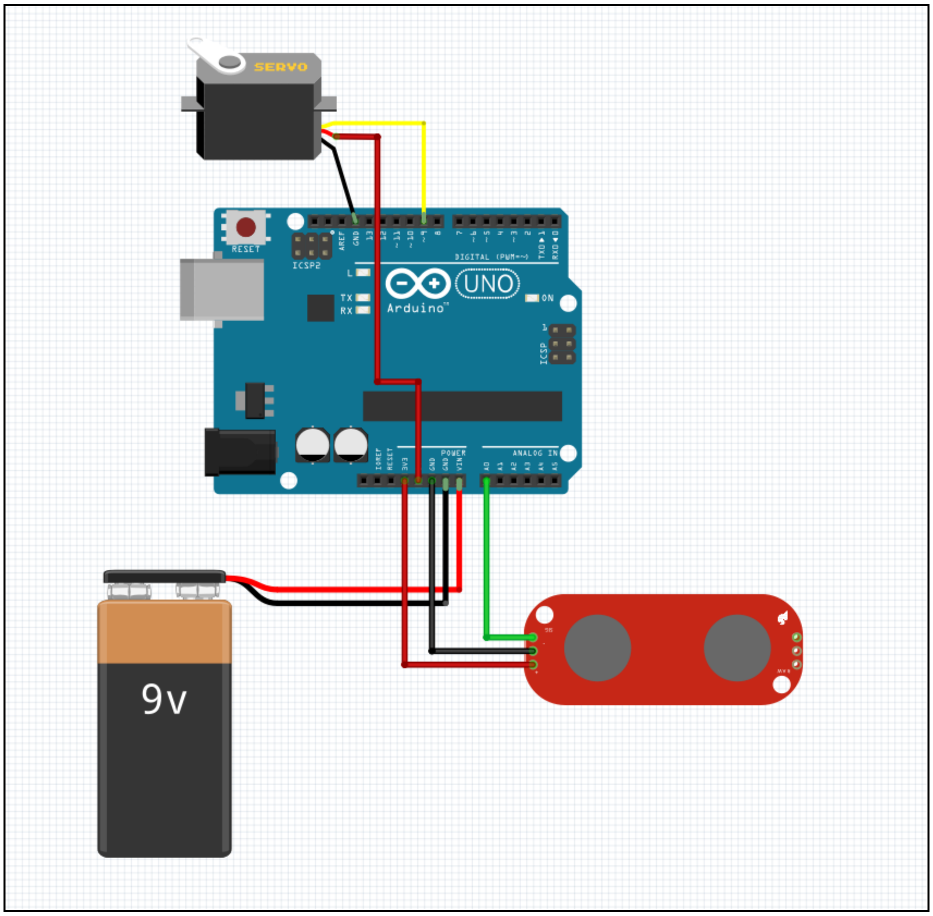


Figure 14: Circuit Diagram (Fritzing)

The muscle sensor is connected to the A0 pin so that the microcontroller can receive analog readings directly from the sensor. It is also connected to the GND pin, which is connected to all the other GND pins across the microcontroller. The sensor is also connected to the 3V3 pin, one that is often used to power low-voltage sensors. The battery is connected on the same side of the microcontroller and is connected to the other GND pin, to establish a connection between the battery, muscle sensor, and motor. The battery is also connected to the voltage-in (VIN) pin, which is used to power the board using an external voltage source. On the other side of the microcontroller, a Servo motor, like the one shown in Figure 15, is also connected to the GND pin, as described previously.

Figure 15: Servo Motor

The motor is also connected to the 5V power pin, which receives the voltage from the 3V3 pin that the sensor is connected to. The motor is also attached to one of the digital pins to receive readings from the analog pin on the other side, connected to the sensor. This allows for a complete circuit between the 9-volt battery, Servo motor, and the Myoware muscle sensor. Fritzing, however, does not support simulations, so another software called TinkerCAD was used to simulate the Arduino code and circuit. TinkerCAD did not support the Myoware muscle sensor, so another component with three similar pins was used, called a potentiometer. Figure 16 shows the potentiometer substituting for the muscle sensor, and the battery and Servo motor being connected in the same exact fashion as the Fritzing model.

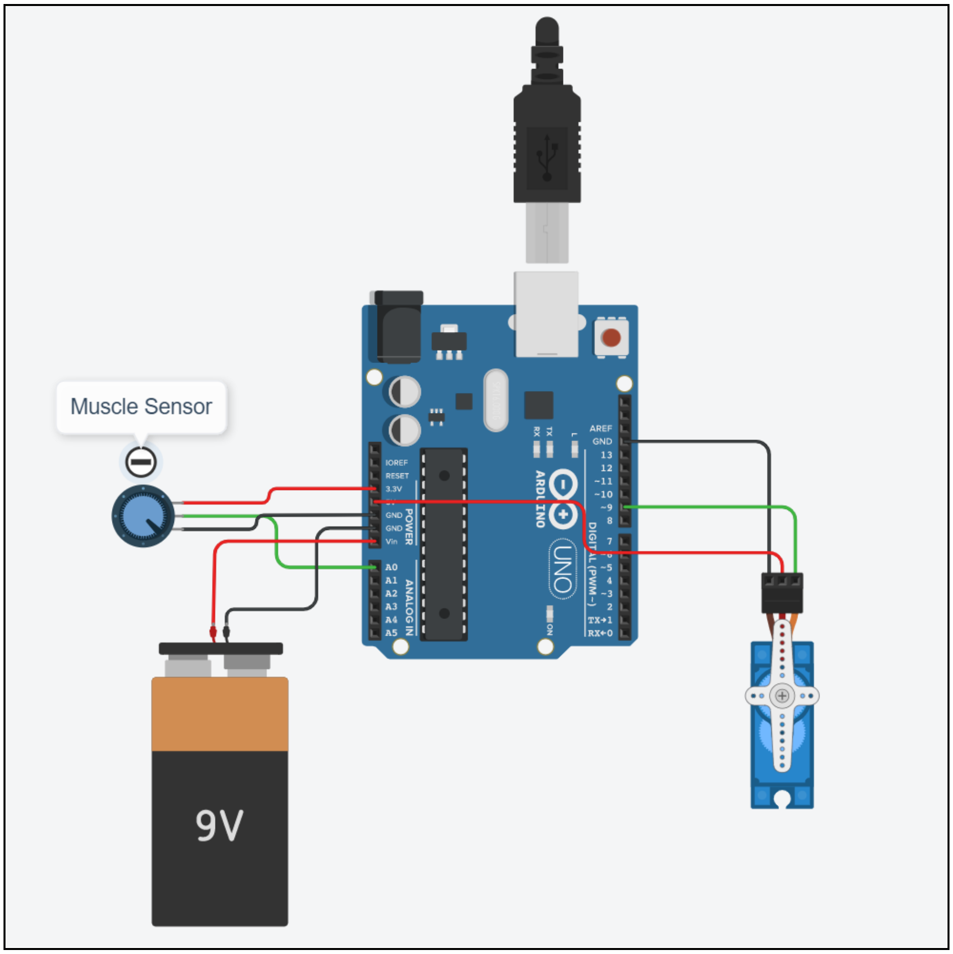


Figure 16: Circuit Diagram (TinkerCAD)

TinkerCAD was used to test the code that was implemented for this project. When simulating the circuit, the Servo motor turned 90 degrees whenever any reading was supplied by the potentiometer. This indicates that the muscle sensor will turn the Servo motor whenever any signals are supplied from the muscle. This is good for this project because it means that whenever a user contracts his muscle, the Servo motor will turn 90 degrees, either rotating an elbow or a wrist joint.

The coding flowchart (Figure 17) demonstrates how the global and setup areas were set up in the Arduino program. The Servo motor, the sensor and output pins, the sensor value, and the voltage were set as constants. The flowchart depicts how the sensorValue variable was set to the input from the pin connected to the muscle sensor (A0). The True/False separation shows that when the A0 pin provides any sort of reading, the Servo motor rotates 90 degrees, and when there is no reading, it rotates back to 0 degrees, or turns -90 degrees. This was the loop area, so that the user can constantly flex his muscles, automatically rotating the prosthetic arm joints.

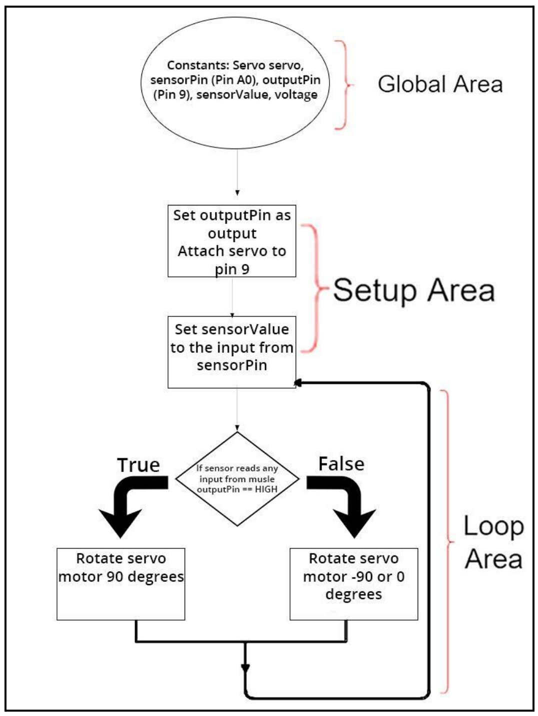


Figure 17: Arduino Code Flowchart

During the implementation of CAD model in fusion 360, we encountered multiple problems. First of all, when duplicating components, computational errors were elicited and components often shifted off place erroneously when edited and manipulated. To address this issue. Two methods were utilized: 1) the joint tool in the assembly section was utilized to constrain one rigid body to another 2) components can be constructed within separate documents that forms a larger project and be later retrieved from the project database.

The only issue encountered while programming the circuit with the Arduino was not having an easy way to directly simulate the Myoware muscle sensor on any online software. Fritzing did not have any form of simulation software, and TinkerCAD did not support simulation of the Myoware muscle sensor specifically. It was impossible for the team to visualize how a reading from the muscle sensor would work and if there were a different method that could be used to get readings from the sensor. The solution to this issue was to use a potentiometer on TinkerCAD and use the exact same code and test if readings were properly converted to a voltage and used to power a Servo motor as desired.

Milestone and Final Product Requirements

Benchmark A required a completed preliminary design investigation. This preliminary report laid out the team's goals and objectives, as well as the initial approach that was agreed upon for the prosthetic arm. The very first cost estimate and project schedule were also submitted as a part of this investigation. Benchmark A also required an initial CAD model, a working sensor, and Arduino code for the sensor, and updated engineering notebook.

Benchmark B required all members to receive soldering training, updates to the previous CAD model, and evidence of controlling at least one motor using sensors. This submission also required the team logo to be approved during the laboratory session and submitted through the 3D printing submission portal.

For commissioning and the final submission, several things were required to be completed. The device needed to complete all the tasks listed in the device choice list, which included being an independent autonomous device without a breadboard that included two of the following: a functioning hand, elbow, or wrist. Sensors need to be fully incorporated into the design and the sensors need to work with one program. A battery with sufficient power also needs to be connected to the circuit.

There were not many times where the group's personalized training because of the online nature of the group. Most of the deliverables were easy to research without help. The only training done was soldering training that was required for the second benchmark. All in all, training was not a very large component to completing this project.

Results

Benchmark A was successfully met on time, as the initial CAD model was developed on TinkerCAD using its 3D design software. The preliminary design investigation was relatively simple, as it simply depicted the preliminary TinkerCAD design and the initial thoughts for a sensor. The first design had only one sensor that was meant to allow for the arm to contract 90 degrees. The sensor was not yet working, as there was no way for the team to simulate the sensor on Fritzing, which at the time was the only software at the team's expense. However, the team was able to find a way to work around this limitation later on in the project, and it did not hurt the team's submission for Benchmark A. The main requirement was that the sensor was agreed upon, and that the criteria was met. Table 1 and Figure 18 shows the team's first illustrations for the cost estimate and project schedule created on Microsoft Project 2019, showing the team's progress from the beginning of the project to Benchmark B.

Table 1: Benchmark A Cost Estimate

Resource	Cost Per Unit	Quantity	Cost
Plastic Printing Material	$0.00	1	0
Arduino Cable	$0.00	20	0
Arduino Uno Microcontroller (SparkFun Redboard)	$0.00	1	0
Battery (9v)	$0.00	2	0
Breadboard	$0.00	1	0
DC motor	$0.00	1	0
Muscle Sensor	$0.00	2	0
Servo (Waterproof, boat/car)	$0.00	1	0
String	$0.00	10	0
Touch Sensor	$0.00	1	0
Projected Labor	$50.00	75	$3,750
Total			$3,750

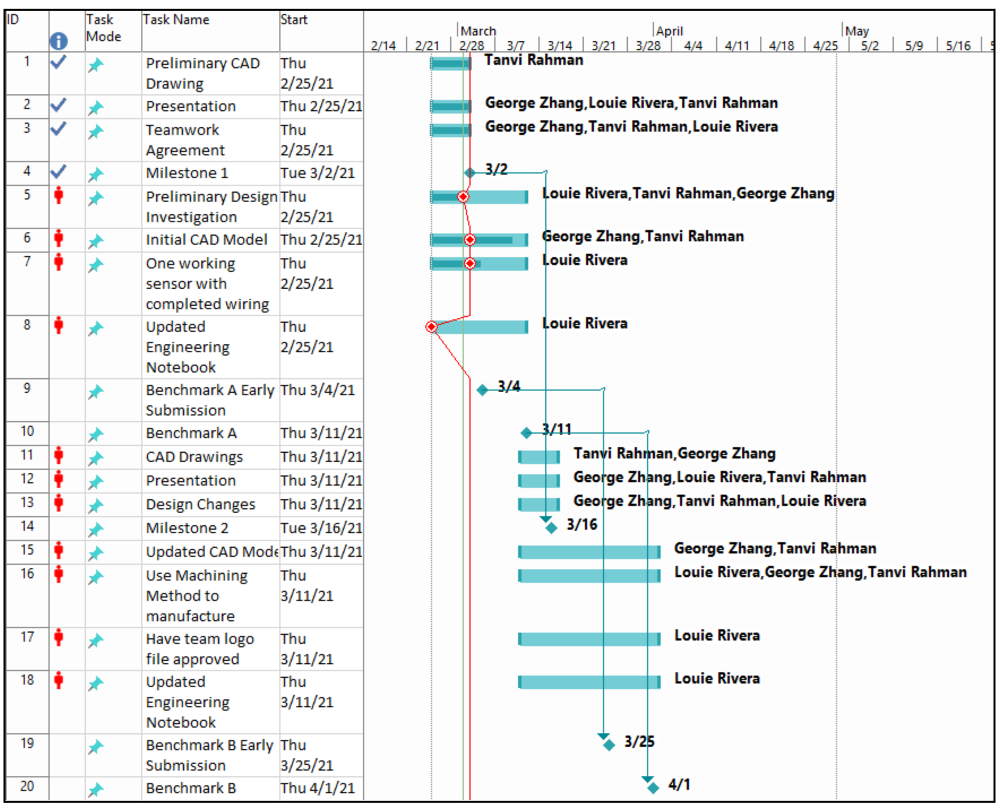


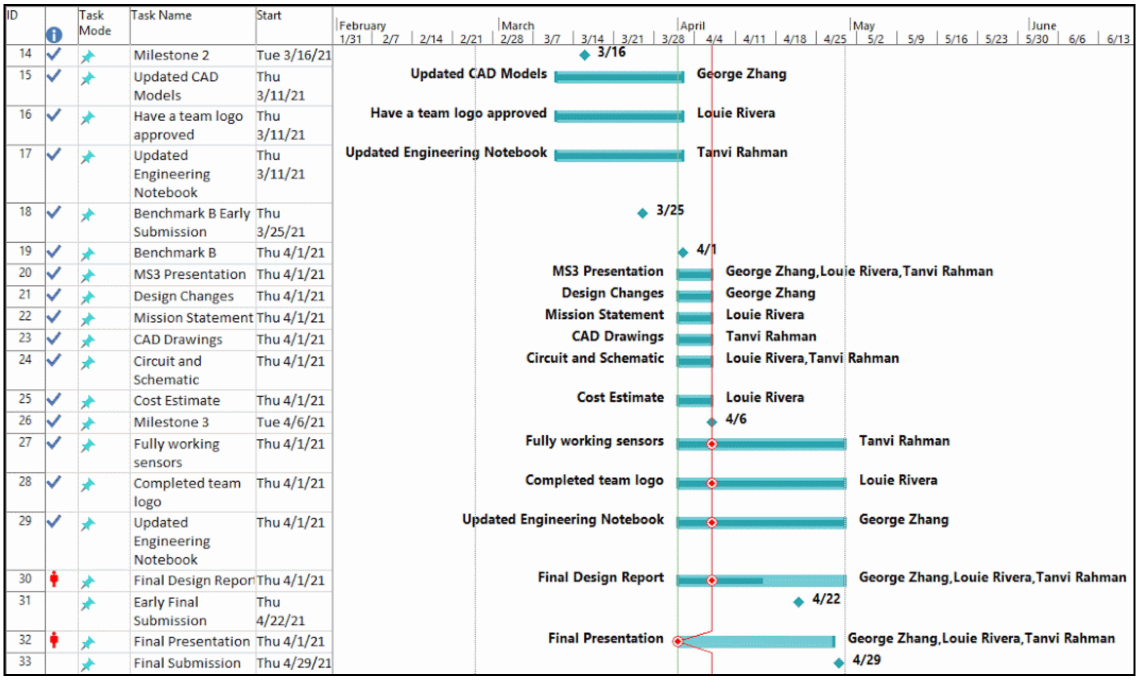
Figure 18: Benchmark A Project Schedule

The team was able to successfully submit Benchmark B early for extra credit. The CAD model for the Spring Soldier was completed on Fusion 360 and was an extremely rudimentary model with room for sensors and cables. The team made many changes to the preliminary design, the CAD model was now colored red and gray and the overall design was much more solidified. It was decided that more sensors were needed for the wrist and fingers in addition to the original design's sensor for the forearm's movement.

Table 2: Benchmark B Cost Estimate

Resource	Cost Per Unit	Quantity	Cost
Plastic Printing Material	$22.99	1	$22.99
Arduino Cable	$5.89	20	$117.80
Arduino Uno Microcontroller (SparkFun Redboard)	$18.79	1	$18.79
Battery (9v)	$6.99	2	$13.98
Muscle Sensor	$37.99	2	$75.98
Servo Motor	$35.99	1	$35.99
String	$7.99	10	$79.90
Projected Labor	$50.00	75	$3,750
Total			$4,115.43

Table 2 shows the updated cost estimate that was submitted for Benchmark B. It shows that the price rose by about $345. Figure 19 shows the updated Microsoft Project schedule, which shows that Benchmark B was successfully achieved, and all of the requirements leading up to that point were also met on time for early submission.



ID	Task Name	Start
14	Milestone 2	Tue 3/16/21
15	Updated CAD Models	Thu 3/11/21
16	Have a team logo approved	Thu 3/11/21
17	Updated Engineering Notebook	Thu 3/11/21
18	Benchmark B Early Submission	Thu 3/25/21
19	Benchmark B	Thu 4/1/21
20	MS3 Presentation	Thu 4/1/21
21	Design Changes	Thu 4/1/21
22	Mission Statement	Thu 4/1/21
23	CAD Drawings	Thu 4/1/21
24	Circuit and Schematic	Thu 4/1/21
25	Cost Estimate	Thu 4/1/21
26	Milestone 3	Tue 4/6/21
27	Fully working sensors	Thu 4/1/21
28	Completed team logo	Thu 4/1/21
29	Updated Engineering Notebook	Thu 4/1/21
30	Final Design Repor	Thu 4/1/21
31	Early Final Submission	Thu 4/22/21
32	Final Presentation	Thu 4/1/21
33	Final Submission	Thu 4/29/21

Figure 19: Benchmark B Project Schedule

Because the project is fully remote, the team encountered multifarious impediments when coordinating working times. First, a 12 hour time zone difference made it hard for team members in New York and in China to communicate and find meeting times that worked for all. A great deal of tolerance and empathy was needed during cooperation. Secondly, there was confusion with some of the requirements and specifications of the project because of the remote nature of the course. The issue was eventually resolved through the coordination between students, TA, and faculties. Finally, because all team members have little or no experience with software required such as Fusion 360, Arduino, as well as TinkerCAD, the initial developmental state was confronted with some adversities. However, through ample amounts of online learning resources, faculty instruction, as well as a dynamic learning mindset, the team gradually caught up and eventually accelerated through the entire project, exceeding expectations and repeatedly completing tasks early for extra credit.

Conclusion

For the final submission of this project, the date for early submission was achieved for extra credit. The finalized Microsoft Project schedule (Figure 20) shows that the team was able to complete all the tasks listed from the beginning of the semester, and that the date for early final submission was met. The project was a success, as the CAD model for the prosthetic arm was fully functional, with an elbow that could bend 90 degrees, a wrist that could rotate 180 degrees vertically and up to 30 degrees horizontally, and finally, a hand that could clench various objects and lift them up and around the air. Page 11 contains the three different views of the final CAD model for the Spring Soldier. For extra credit an animation was also created with the arm to show how it would work when assembled. This animation illustrated how the arm would move its fingers if it were assembled. These animations can be seen on slides 9 and 10 on the team's [final presentation](). Using TinkerCAD and the Fritzing software Brooklyn Bionics was able to successfully illustrate how the sensors and motors would work in real life had the arm actually been assembled in person.

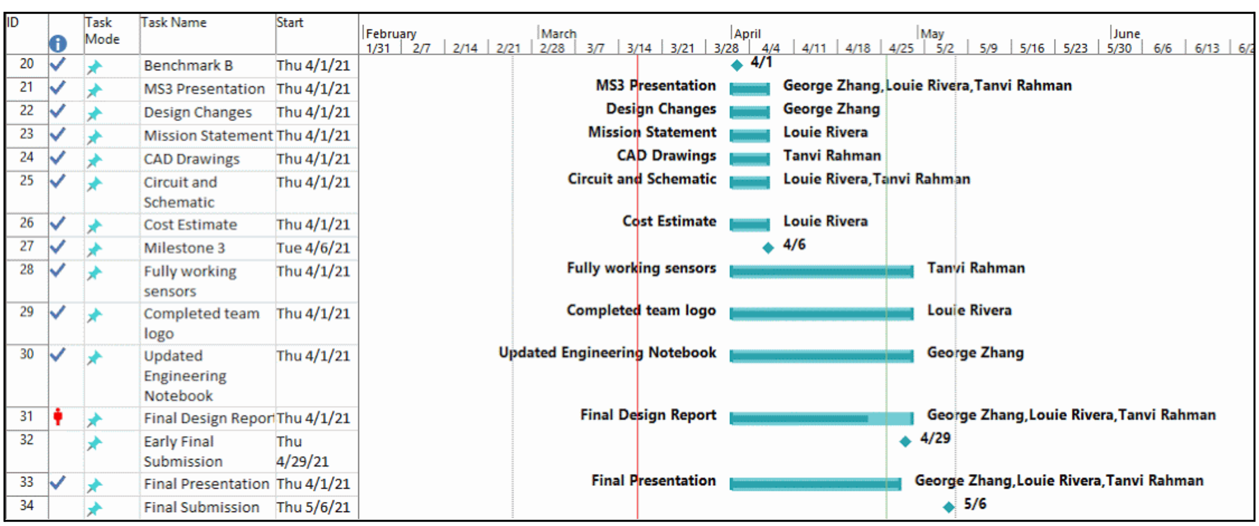


Figure 20: Final Project Schedule

The team was also successful in achieving the more morally fulfilling objectives of this project: creating a prosthetic arm that was just as functional, but significantly more affordable than leading brands of prosthetic limb companies. Most cosmetic prosthetics cost around five thousand dollars, and functioning prosthetics with hooks cost about ten thousand. Prosthetics with the latest muscle sensing technology like the Spring Soldier cost upwards of twenty thousand dollars. The Spring Soldier is not only just as reliable and functional, but is also over five times more affordable, as seen in the final cost estimate (Table 3).

Table 3: Final Cost Estimate

Resource	Cost Per Unit	Quantity	Cost
Plastic Printing Material	$23.00	1	$23.00
Arduino Cable Pack (40 wires)	$6.00	1	$6.00
Arduino Uno Microcontroller (SparkFun Redboard)	$19.00	1	$19.00
Battery (9V)	$7.00	2	$14.00
Muscle Sensor	$38.00	2	$76.00
Servo Motor	$36.00	3	$108.00
String	$3.99	1	$4.00
Projected Labor	$50.00	75	$3,750
Total			$4,000.00

This illustrates the success of the team in developing a fully functional prosthetic arm that proved to be over five times as affordable as its competitors. The team strived to make it available to all amputees and people with disabilities, and hopes to begin distribution of the soldier for a low price of four thousand dollars.

Further improvements

Although the prosthetics achieved considerable technical triumph in terms of cost, manufacturing, and functionality, several limitations were found in the design.

Firstly, the Electromyography (EMG) sensor used in this prosthesis is only functional if the user has a relatively intact nervous system. That is, the peripheral nerve branches that control the muscle have not yet been destroyed by amputation. This is actually rarely the case for amputees. Therefore, future works in neuromechanics and neural interfacing technologies that can link prosthetics to the central nervous system so that the prosthetics can enable full rehabilitation of sensorimotor control

Secondly, prosthetics do not provide haptics and proprioceptive feedback. Haptics, defined as the sensation that provide information about contact force acting on the fingers, is provided through the skin and communicated through peripheral nervous systems. Proprioception is a human's capability to perceive the angular position of joints without the aid of visual information. These two types of sensorimotor feedback are the essence of human sensorimotor perception. Therefore, future work on bidirectional Neural interfaces is needed to help patients achieve complete rehabilitation of sensorimotor functionalities.