

Assistive Tension Device

Team Tension

GEEN 2400: Projects for the Community

Fall 2023

Abstract

Mobile arm supports are devices used by individuals with limited upper-extremity mobility and strength to support their limbs in everyday activities. JAECO Orthopedics expressed that their mobile arm support product, the MultiLink Mobile Arm Support, lacked a way for clients to change the amount of applied assistive tension without the help of a caretaker. This restricts the independence of the client and increases the reliance on a caretaker for everyday tasks. After discussing the design requirements and parameters of the desired product with JAECO, I assembled a team of interdisciplinary engineers in my “Projects for the Community” course. We set out to solve independence issues in JAECO’s product by creating a device that allows clients to independently change the assistive tension of the MultiLink Arm Support. The motorized tensioning device we designed allows clients to experience more freedom and improve quality of everyday life.



Figure 1: Tensioning device attached to JAECO MultiLink Mobile Arm Support

Client Information and Background

JAECO Orthopedics specializes in manufacturing and assistive orthopedic technologies. JAECO has supplied quality upper extremity orthotic equipment to the rehabilitation field worldwide and continues to develop new assistive technologies. JAECO’s myriad of products aid in activities of daily living for a variety of upper limb pathologies, such as muscular diseases, cerebral palsy, spinal cord injuries, multiple sclerosis, and amyotrophic lateral sclerosis. Although JAECO’s products are effective in increasing mobility and independence, they still require clients to have a degree of dependence on caretakers to operate effectively. For example, JAECO’s Multilink Arm Support requires caretakers to put on and take off the rubber bands used to change the assistive tension. We decided to create an electronic tensioning system which allows clients to use the Multilink Arm Support completely independently.

Design Requirements

- Supports the weight of a human arm
 - This is the minimum requirement for our product to be useful.
- Space-conscious design
 - Product should not interfere with everyday life or movement of clients. Inhibiting the clients' movement would limit their independence and therefore be counterintuitive.
- Cost-efficient prototypes
 - JAECO Orthopedic products are covered by medical insurance, so they asked us to make the prototype cost-efficient so it would be easier for insurance to cover.
- Easy to install
 - Improves ease of use for clients and helps clients become independent.
- Durable/ long-lasting components
 - Product needs to be strong and be able to withstand force for a considerable amount of time. Components, like batteries or springs, need to last a long time.
- Easily Attainable Materials/Components
 - JAECO expressed a desire to possibly mass manufacture a prototype. That means we needed to use easily attainable materials to help expedite the production process.
- Sustainability
 - Prototype would preferably be easily recycled, reused, or repaired. This allows the prototype to be used for longer periods without needing to be replaced.

Overview of Design Process

The device utilizes a worm gear motor powered by a nickel-metal hydride battery, with logic and feedback controlled by an Arduino Nano microcontroller. The Arduino Nano is capable of Bluetooth communication, precise motor control, and safety shutdown control. The worm gear motor actuates the MultiLink Mobile Arm Support via displacement of a paracord rope and a thick alloy steel spring using a 3D-printed spool attachment. A worm gear was chosen to drive our tension mechanism due to its built-in capability to prevent opposing rotation of the motor unless current is supplied. Additionally, our safety shutdown mechanism uses a switch to disable electronic capabilities when the rope has been displaced past its calculated safety limit. These components are encased in a 3D-printed enclosure with a transparent acrylic lid, with multiple different washers and fasteners securing the tension device to the multilink arm. Figure 2, seen below, displays our tensioning device prototype with all of the aforementioned components.

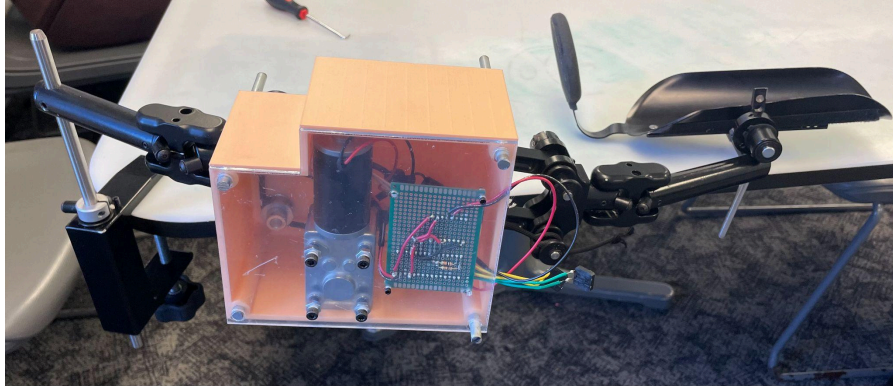


Figure 2: Tensioning device attached to JAECO MultiLink Mobile Arm Support (Prototype)

A multitude of engineering principles were used in the development of our product. With the purpose of our device being to increase tensile force acting on a multi-link assembly, a combination of static force analysis, CAD design, and electronic circuit development were used in our product design.

Static force analysis was necessary in order to develop a relationship between the tensile force applied through our device and the assistive torque applied to the multilink arm. Figure 3 pictured below displays a free-body diagram analyzing the relationship between these two forces. Equations for tensile force were developed, as well as the amount of tension that would need to be applied to provide torsional assistance to an arm of average human weight. This analysis was especially useful in the initial design phases. We decided to avoid a design that would exert an applied moment around one of the pins as this would create an additional bending moment within the arm linkages of JAECO's device.

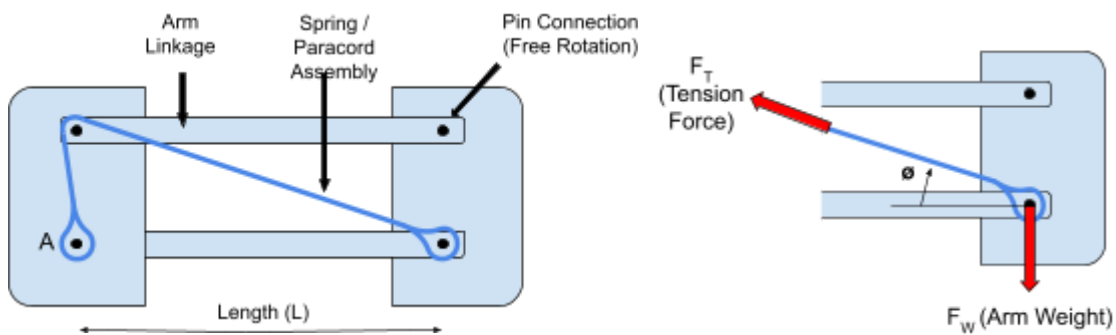


Figure 3: Diagram of Multilink Arm Assembly & FBD of Static Forces Acting on Linkage

We used computer-aided design (CAD) software extensively for a variety of components in our device. Having strong CAD software skills and understanding the fundamental principles of 3D printing allowed us to fabricate components of our device, including the encasement, string channel collars, and the worm gear spool. Additionally, engineering design practices such as

space optimization, component configuration, and ease of use were all considered during the process of CAD modeling. Figure 4 below displays CAD assemblies of two critical components: the encasement and spool. Appendix A contains more detailed angles for the encasement.

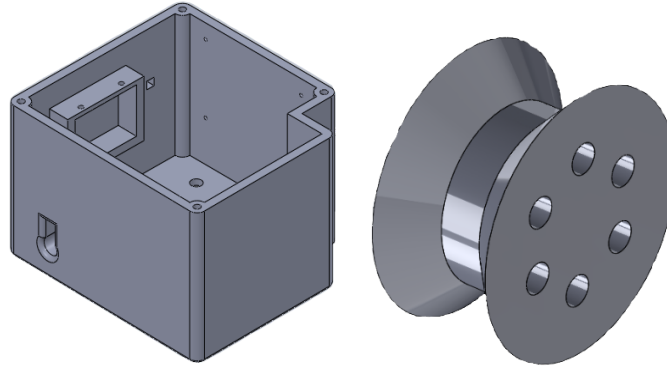


Figure 4: CAD models for encasement and spool components.

Finally, electronic circuitry principles were applied to design components, allowing for the powering of mechanical devices, physical and remote control of devices, and emergency shutdown mechanisms. Knowledge of principles including Ohm's law, motor control, and digital logic (Arduino) was required for the fabrication of the electronic components of the device. Figure 5 below displays a schematic diagram of all electronic components.

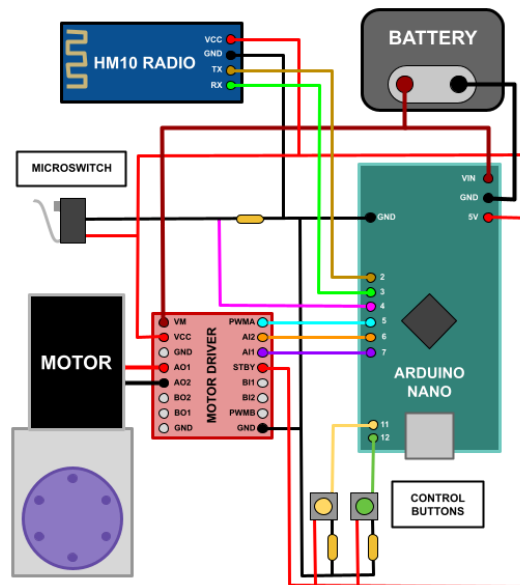


Figure 5: Electronics schematic.

Personal Contributions

Projects for the Community is an engineering design course uniquely designed to not only give students the opportunity to have hands-on experience innovating, but also learn more about the communicative aspects of the engineering industry. Rather than having a list of potential clients prepared for us, we were tasked with reaching out to individuals and companies ourselves. Our team had previously decided to find a client in need of assistive technology, and we were fortunate enough to have made this decision right before an assistive technology exposition in a neighboring town. The exposition had around thirty to forty companies presenting their groundbreaking work, and we had pinpointed about eight companies of interest beforehand. I was responsible for giving our “elevator pitch” at each stand, exchanging contact information, and taking notes about client problems and potential areas of improvement of existing technology.

After we had narrowed down our list of potential industry partners to around five individuals and companies, I contacted each of them and organized times for my group to meet with them. Throughout the process, I remained the main point of contact between our team and our potential partners. Once our team decided that we would be most successful in creating a working tensioning prototype for JAECO’s Multilink Arm Support, I continued to be the bridge between our team and JAECO. I coordinated with Mr. Robert Jones, JAECO’s Vice President of Operations, about logistical aspects of our design process such as ensuring that the Multilink Arm Support was shipped and delivered on time for our group to begin creating our electronic tensioning system. I also communicated with Mr. Robert Jones periodically to give him updates and schedule a time for him to come visit Boulder to see our prototype in person.

In addition to ensuring our project was logistically-sound, I researched power supplies for our tensioning system. Since mobility was one of our higher priorities I decided that a rechargeable power source, rather than a wall plug, would be most ideal. I also wanted to consider the sustainability and safety of our power supply, as well as other parameters such as charge time, longevity, and size. I eventually narrowed down our options to nickel-metal hydride batteries, lithium-ion batteries, and nickel-cadmium batteries. A nickel-metal hydride battery proved to be the most ideal for our purposes for the following reasons:

- They are unlikely to combust due to thermal runaway.
- They can be recycled once they’ve died
- They can be fully recharged between 500-800 times and don’t have a memory effect
- They are unlikely to overheat to a temperature that could cause bodily harm.

While nickel-metal hydride batteries tend to have weak-cell syndrome, this wasn’t an issue for our tensioning device since the worm-gear motor didn’t require a constant power output to function.

Once my team and I created a proof of concept for the tensioning system, we began fine-tuning the encasement for the system. I created several iterations of our system's housing using computer-aided design software (SolidWorks), and prioritized spatial optimization to ensure that our device was as unobtrusive as possible. I first decided to mount our circuit board on the wall adjacent to the encasement's connection point with the Multilink Arm Support to eliminate the majority of the horizontal bulk of the encasement. I then created a prototype of two "shelves" which each side of the worm gear would rest on. This was done using two thin planks of plywood which I roughly cut in the University of Colorado's wood shop (using a miter saw and a band saw) to fit within a previous iteration of the encasement. I used these rough prototypes to physically confirm that the idea was feasible before taking it back to SolidWorks, where I created the shelves within the encasement and a model of the worm-gear motor to fine-tune all of the dimensions within an assembly. I coordinated with my teammate who was primarily responsible for our electrical work to ensure that our safety switch had proper housing within the encasement—and that the locations and number holes for the buttons and battery wire coincided with their positions on the circuit board. Finally, I used the Integrated Teaching and Learning Laboratory's Lulzbot 3D Extrusion Printers to print out the encasement iterations.

When it came time to show our tensioning device at the University of Colorado's Engineering Design Exposition, I volunteered to be the predominant speaker during our presentation. Because I often delineated tasks to my team members and ensured that we were organized and on-schedule, I was able to easily summarize our design process as well as our relationship with JAECO, the desired clientele, and the problems our device solves.

Testing Procedures

Tensile force analysis was used to determine the tensile strength characteristics of the paracord/spring assembly. Through the use of an MTS tensile strength testing machine, we were able to develop graphs that displayed the relationship between tensile force and string displacement. The purpose of this testing was to determine the precise spring constant value of our paracord/spring assembly. Figure 6 below shows the testing procedure used to measure the spring constant of our assembly.

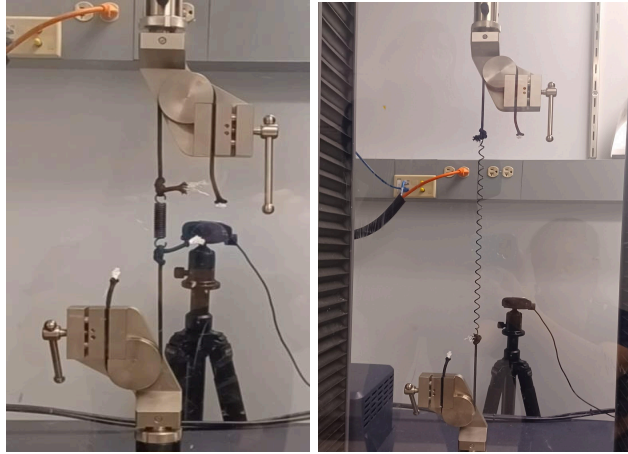


Figure 6: Spring / paracord assembly before and after tensile strength testing

Results

With the knowledge of the spring constant of our paracord and spring assembly, we were able to develop equations of tensile force per unit of string displacement. This equation is crucial for our design in order to understand how much assistive torque is produced per revolution of the worm gear and spool assembly. Furthermore, using previous static force analysis, we were able to determine the tensile force necessary for our device to supply in order to support the weight of the average human arm. Figures below display corresponding graphs, variables, and derived equations for the conducted tensile strength testing.

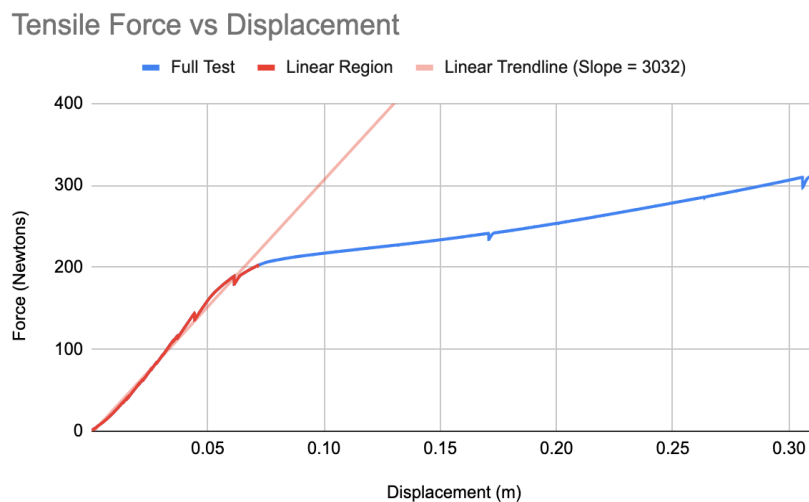


Figure 7: Tensile Force vs Displacement Graph

Variable	Quantity & Units
F_T	Tensile Force (N)
F_w	Arm Weight (N)
M_A	Moment About Pin A (Assistive Torque)
x	Linear Displacement (m)
k	Spring Constant (N/m)

Variable	Quantity & Units
r	Spool Revolutions
d	Spool Diameter (m)
L	Arm Linkage Length (m)
θ	Angle Between Bottom Linkage and Rope

(7.1)	$k = \text{Slope} = 3032 \text{ (N/m)}$
(7.2)	$F_T = kx$
(7.3)	$F_T = k \cdot \pi dr$
(7.4)	$M_A = F_T \cdot \sin(\theta) \cdot L$
(7.5)	$M_A = \pi drk \cdot \sin(\theta) \cdot L$

Figure 8: Variables and Derived Equations

The derived equations above allowed us to determine how many spool revolutions, driven by the motor, will result in sufficient assistive torque applied to the MultiLink Arm. Plugging in known values for the above variables and solving for variable “r” (assuming total moment about pin A is equal to 0) results in the following conclusion: the tensile force required to hold the unassisted weight of the average human arm (10 lbs) is 170 newtons. Furthermore, this tensile force can be equated to 0.47 revolutions of the spool. Finally, since the tensile test was performed with springs and paracord identical to those used in the device, it should be able to withstand tensile forces of at least 312 N (70 lb) or greater without failing and putting the user at risk. As shown by the transition from the elastic to plastic regions of the graph, the spring should also withstand forces of up to around 200 N (45 lb) before undergoing permanent deformation.

Conclusions & Future Work

Following our testing and analysis, we can evaluate multiple ways in which to improve our product. Most importantly, an understanding of the relationship between spool revolutions and assistive torque applied will allow us to reorganize components within the encasement more efficiently. For example, with our newfound understanding, we will be able to determine precise locations to insert our safety shutdown mechanism as well as where to attach the spring to the paracord. These further improvements will ensure the durability and robustness of our product.

Throughout this project, we used several engineering principles to accomplish our overall objective of supporting the weight of the MultiLink Mobile Arm Support with the force load of a human arm. We used concepts of force analysis and electronic circuitry in the implementation of a tensioning device to provide independence in daily activities for individuals with limited mobility in their arms.

Our team learned a plethora of lessons and concepts after working through many difficulties and hardships. This includes the following:

- Troubleshooting SolidWorks errors
- Understanding material strengths and weaknesses and therefore how to best tailor material properties of device components to best fit their individual needs
- 3D printing techniques
- Creating appropriate tolerances
- Better understanding the iterative design process

As a result of our testing and analysis, we also gained insight on future improvements. This includes moving our electronic set (eg: motor driver, microcontroller, & connections) to a PCB Board. This would lower the space that the circuits take up. The spool was the major failure point in our prototype, so moving to a metal spool would likely remove or lessen the failure point of that component. This would vastly increase the durability and longevity of our tensioning device. Our prototype is proof that an electronic tensioning system which can be controlled independently by clients is feasible under the parameters set by JAECO Orthopedics. We're hopeful that our proof of concept can continue to be improved upon and eventually be mass-produced to become accessible to all MultiLink Arm Support clients.

Appendix A: CAD Models

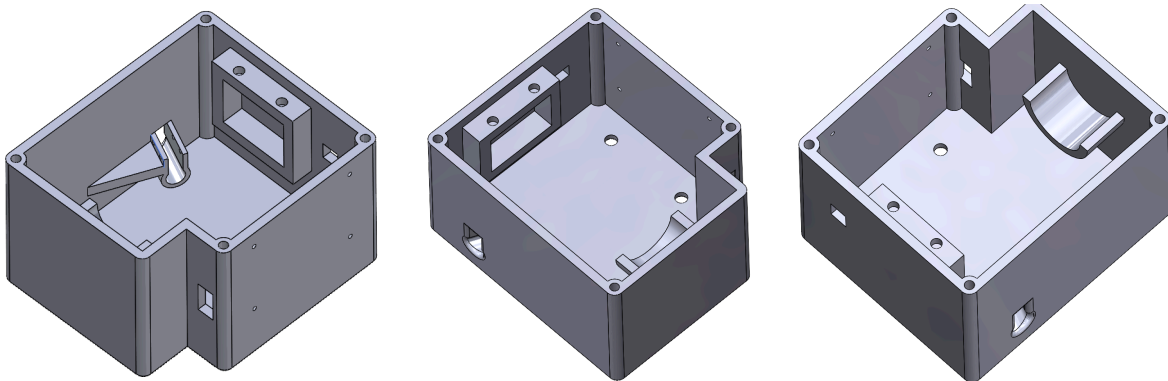


Figure A1: Different angles of the encasement of the device.

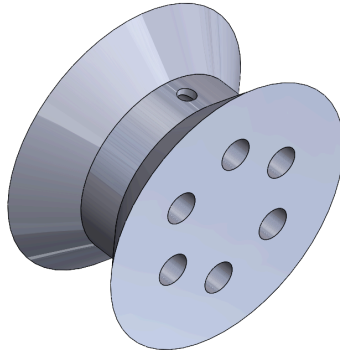


Figure A2: Spool holding string.

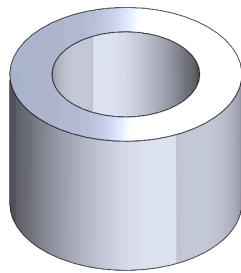


Figure A3: Collar providing spacing between the washers that held the string in place.

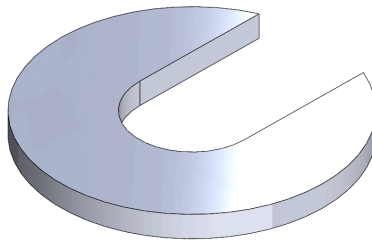


Figure A4: Spacer used to ensure a tight fitting for the motor in the encasement.

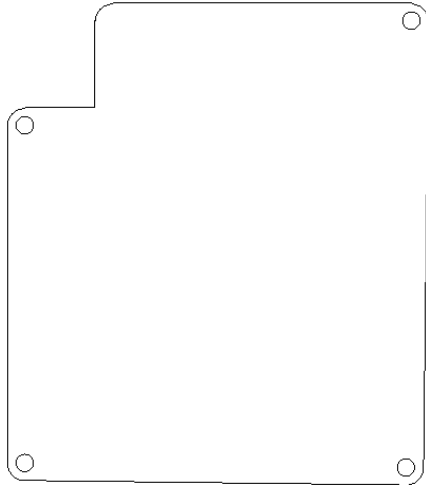


Figure A5: Sketch of top acrylic plate.

Appendix B: Code

The main function of this code evaluates button and Bluetooth data inputs on a case-by-case basis and drives the motor accordingly. The motor uses the universal L298N library used for most DC motor drivers. When reading a high signal from the buttons, the code checks whether the safety switch is triggered and drives the motor forward or backward if the switch is off, or only backward if the switch is on. Here, the Dabble library and functions are responsible for processing Bluetooth inputs. Assuming no buttons are being pressed and the safety switch is off, Bluetooth input is interpreted and translated to motor control outputs.

```
//Dabble definitions
#define CUSTOM_SETTINGS
#define INCLUDE_MOTORCONTROL_MODULE

// Include motor driver and Dabble libraries
#include <L298N.h>
#include <Dabble.h>

// Pin definition
const unsigned int PWM = 5;
const unsigned int IN2 = 6;
const unsigned int IN1 = 7;

const unsigned int button1 = 11; //Yellow
const unsigned int button2 = 12; //Green
bool button1State = 0;
bool button2State = 0;

const unsigned int safetySwitchPin = 4;
bool safetySwitch = 0;

// Create one motor instance
L298N motor(PWM, IN1, IN2);
int motorSpeed = 250;

// Set up Dabble motor control
motorControls Control = motorControls(PWM, IN1, IN2);

void setup()
{
  // Begin serial communications
  Serial.begin(9600);
```

```

// Start Dabble
Dabble.begin(9600);

// Set initial speed
motor.setSpeed(70);

//Initialize buttons and safety switch
pinMode(button1, INPUT_PULLUP);
pinMode(button2, INPUT_PULLUP);
pinMode(safetySwitchPin, INPUT_PULLUP);
}

void loop()
{
  button1State = digitalRead(button1);
  button2State = digitalRead(button2);

  safetySwitch = digitalRead(safetySwitchPin);
  //Serial.println(safetySwitch);

  Dabble.processInput();

  if(button1State && button2State)
  {
    motor.stop();
  }
  else if(button1State)
  {
    //Serial.println("Motor is running forward!");
    motor.backward();
    motor.setSpeed(motorSpeed); //Unwinds spool
  }
  else if(button2State && !safetySwitch)
  {
    //Serial.println("Motor is running backward!");
    motor.forward();
    motor.setSpeed(motorSpeed); //Winds spool
  }
  else if(!safetySwitch)
  {

```

```

Control.runMotor1();
}
else
{
    motor.stop();
}
delay(10);
}

```

The code block diagram below summarizes the functions of the code.

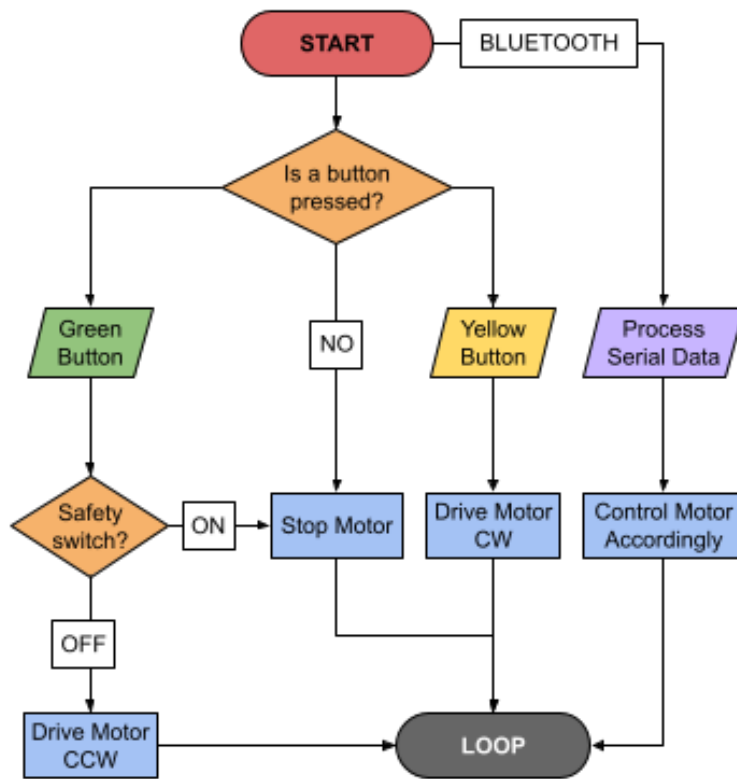


Figure B1: Code block diagram.

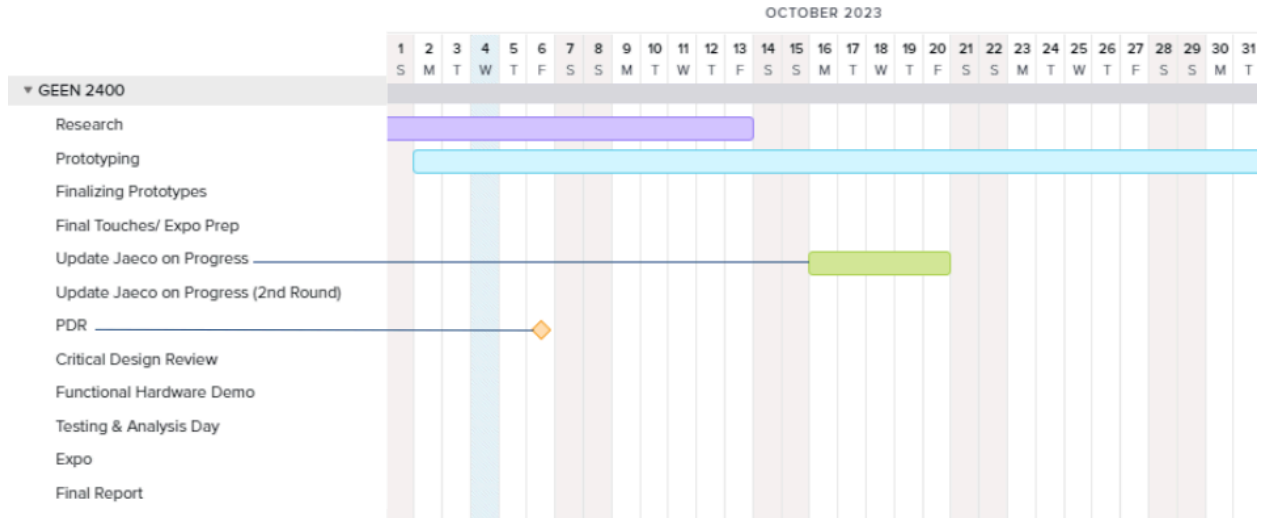
Appendix C: Budget/ Bill of Materials

Material	Quantity	Cost
Worm Gear Motor	1	\$28.99
Stop Collars (.25")	2	\$6.58
Paracord	1	\$7.99
Acrylic Sheet	1	\$5.00
Battery with Charger	1	\$44.50
Threaded Dowels & Nuts	4	\$3.60
Arduino Nano	1	\$26.00
Motor Driver	1	Free
PLA	N/A	Free
Prototyping materials (springs, plastic gears)	N/A	\$34.27
Total	N/A	\$156.93

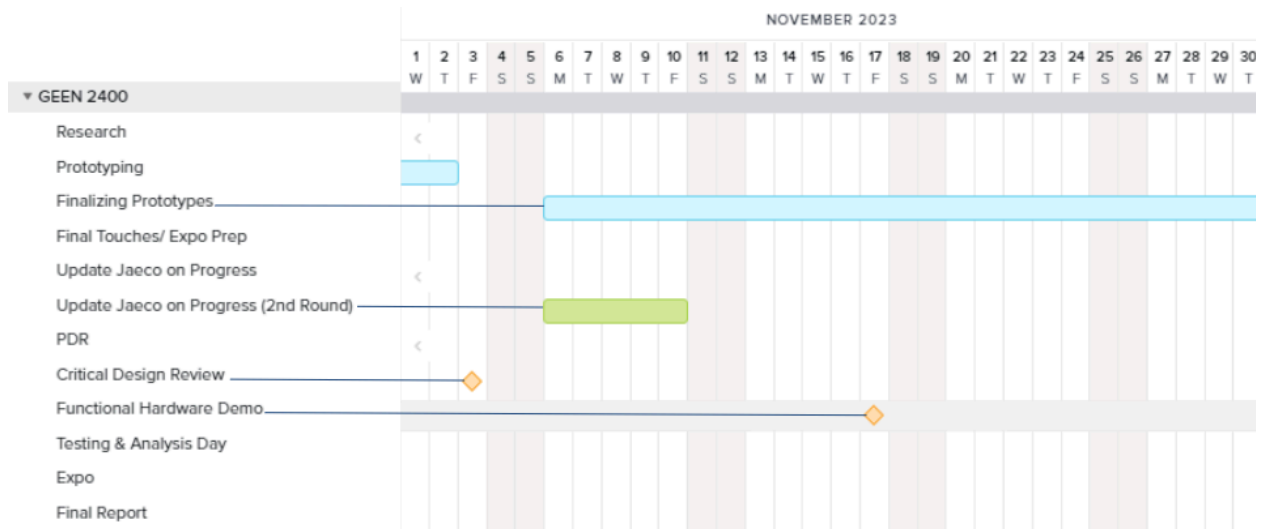
Appendix D: Project Timeline

September: Finding a Client/ Pretotyping

October (Figure D1):



November (Figure D2):



December (Figure D3):

