GNG2101

Design Project Progress Update

TEAM FLEX TECH E1.2

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List of Acronyms and Glossary

Table 1. Acronyms

Acronym	Definition
BOM	Bill of Materials
CAD	Computer Aided Design
UPM	User Product Manual

Table 2. Glossary

Term	Acronym	Definition
Bill of Materials	BOM	Table or list containing cost of each component of a system.
Computer Aided Design	CAD	Refers to software programs that draft both 2D and 3D designs.
User Product Manual	UPM	Refers to the entire document.
Medium-Density Fiberboard	MDF	A collection of highly compact recycled woodchips formed into a board for construction.

1 Introduction

Project Deliverable E goes over our first prototype, along with a 10-minute presentation detailing the progress we made over our previous deliverables and explaining the goals of our first prototype. We first outline the prototype test plan which will be used to determine what unknowns we would like to test in our idea. Once created, we then create our prototype 1, and we finally test it against our expected values for our target specifications. We can then compare the expected values with the actual values and make a decision on what should be changed.

Project Deliverable F goes over our second prototype, which helps us prepare for client meet 3. We develop this second prototype based on improvements from the first prototype and follow the same structure as Deliverable E including target specifications, documentation of construction and assumptions needed to be validated. We finally create a final presentation to show our client to gather as much feedback on the new design as possible.

2 Prototype 1, Project Progress Presentation, Peer Feedback and Team Dynamics

2.1 Prototype 1

2.1.1 Prototype Test Plan #1

For our first prototype, we want to validate and test the following elements:

- **Can the device support the weight of a human foot (Design for Safety, Reliability).**
    - We want to see if the structure of our device is sufficient to support the weight of one's foot. The prototype we have developed utilizes a trapezoidal base that receives the weight of the device and user, so we will test if the device remains stable after a variety of positions the user will undertake on the device.
- **The useability of the device when the user is lying or sitting down (Design for Safety, User Experience).**
    - The client will use the device while lying down (sometimes sitting too). We will test if the device collapses under these conditions and observe any unforeseen consequences good or bad from using the device in these positions.
- **The ergonomics of the range of motion (Design for Safety, User Experience, Reliability).**
    - Since our device can dorsi/plantar flex the foot at a small power output, we want to test whether there are any ergonomic issues when a user uses the device. This can range from uncomfortable positions to extreme angular tension, or even unnatural movement of the foot. This is an important factor to take so we can design the main frame of our device early and use the base as the foundation for our future prototypes (which will most likely have stronger materials).
- **The required force of the motors (Design for Safety, User Experience).**

- Since our device requires external force to dorsi/plantar flex the foot, we need to measure the required power output that is required to move the foot. We can test this by using the Wizard of Oz Method and manually moving the dorsi/plantar flex portion of our device to get an estimate of how much power is required to move the foot.

2.1.2 Prototype 1 Documentation

When creating our first prototype, we've documented many things such as a CAD model, a detailed design, a flow chart explaining the user experience and an Arduino circuit diagram.

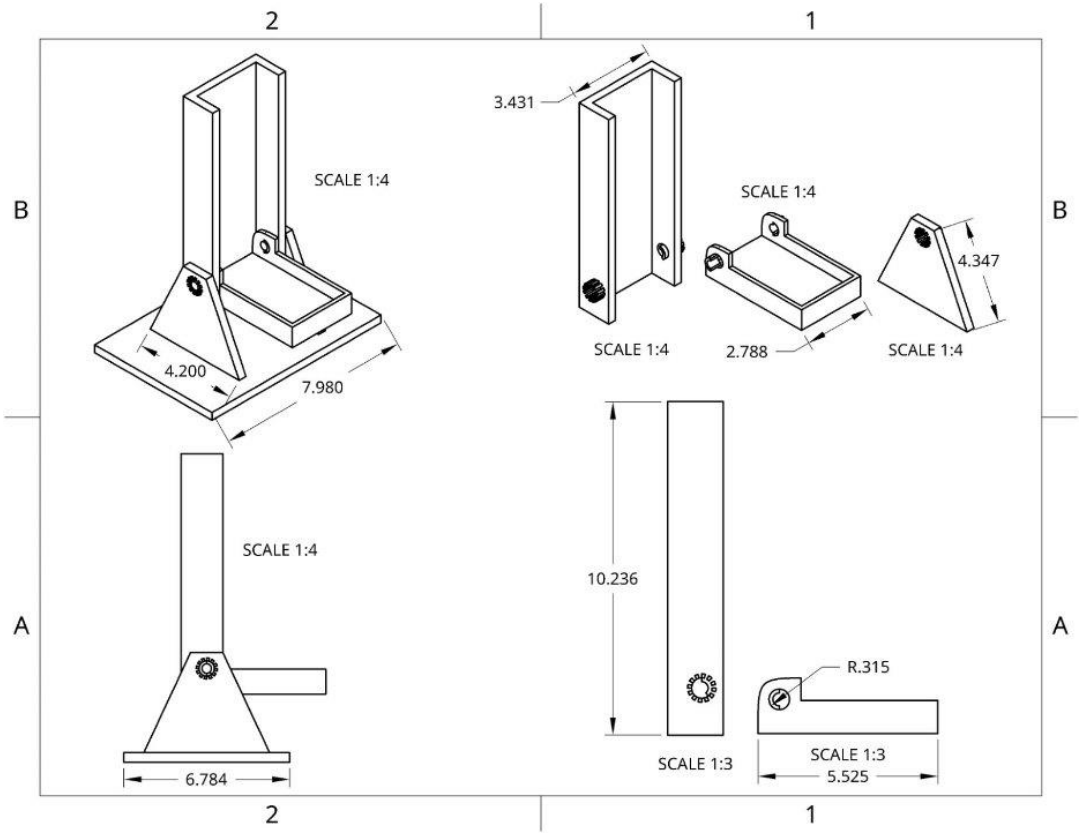


Figure 1: Parts Drawing of CAD Model

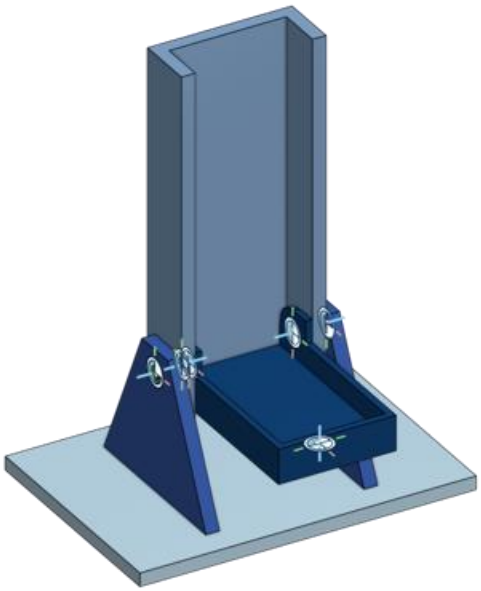


Figure 2: CAD Model of Prototype 1

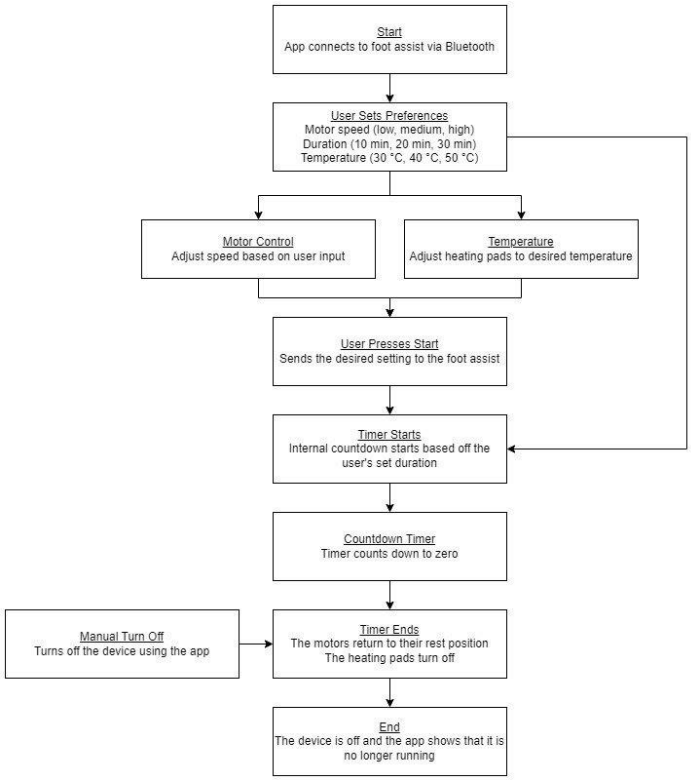


Figure 3: Flowchart for Prototype 1

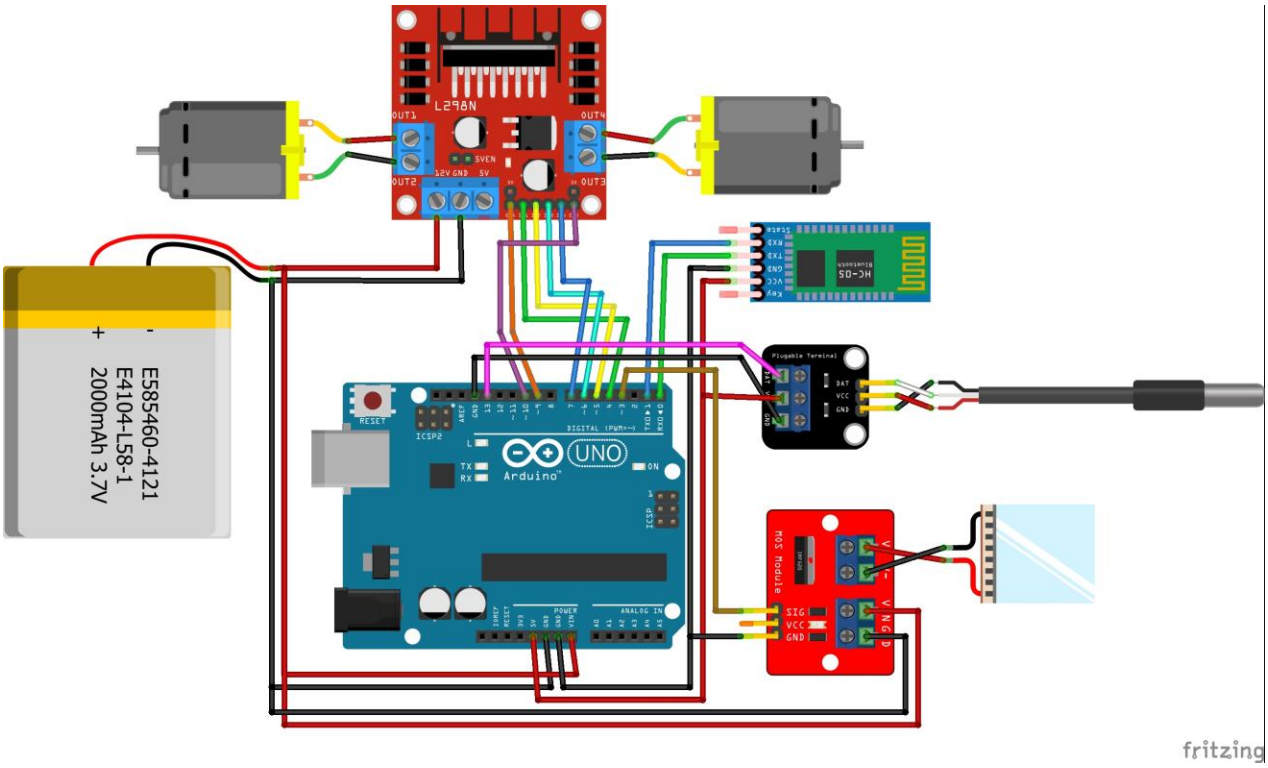


Figure 4: Arduino Circuit Diagram

2.1.3 Target Specification Evaluation

The prototype has a rigid structure to support the client's foot and allows it to rest comfortably. The angle at which the foot assist can be positioned supports use while sitting or lying down as desired. It has a full range of motion of approximately 40-degree dorsiflexion for a maximum range of motion and muscle training. Heating pads also accompany the interior of the foot flexor for muscle relaxation and therapy. The foot assist is designed to be controlled via an iOS application which will allow the user to adjust the duration, speed, and temperature of the device while it is active. The entire application will be powered by a rechargeable battery which supports portability and ease of use wherever it may be used. Overall, the prototype meets the client's interpreted needs and satisfies the problem statement. Our team continues to iterate and further develop better prototypes as feedback is received.

Target Specification	Unit	Expected Values	Actual Values
Load Capacity	Kg	6	~8
Flexion Angle when Lying or Sitting	Degrees (°)	40	50
Ergonomic Range of Motion	Degrees (°)	40	50
Motor Force	Newtons Meter (Nm)	10	3

2.2 Project Progress Presentation

Project Progress Presentation (TA's and PMs).pptx

2.3 Project plan update

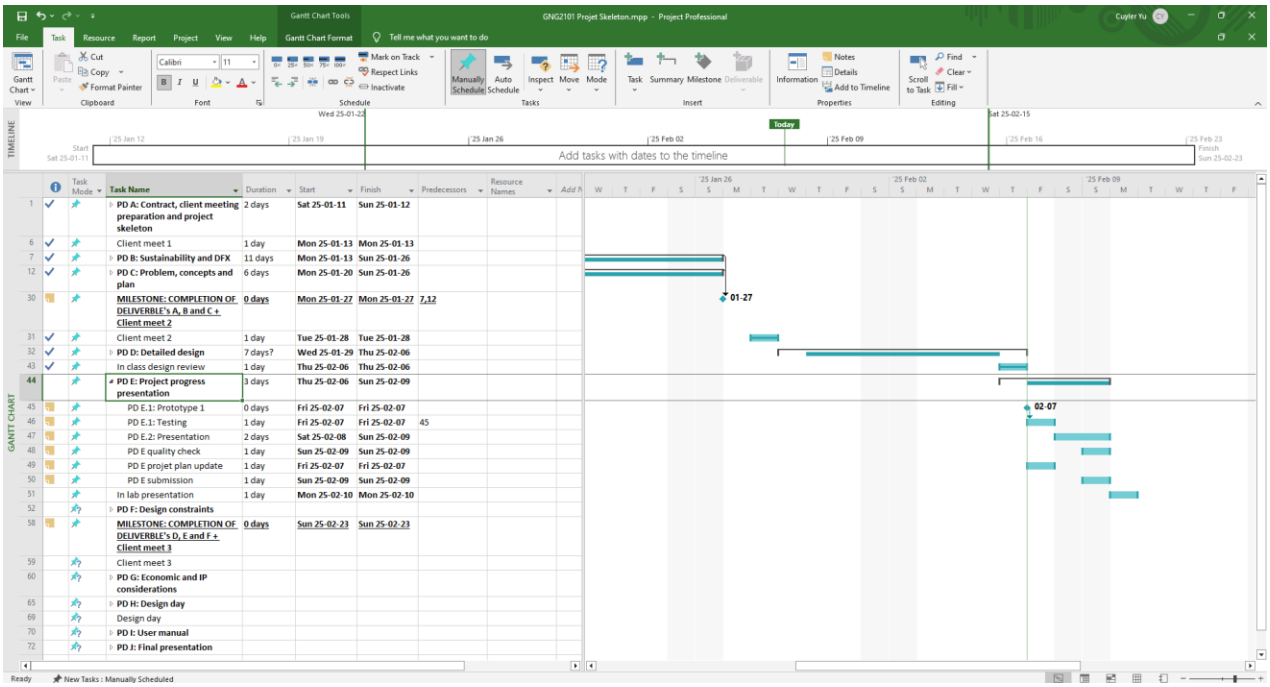


Figure 5: Gantt Chart PD E

3 Design Constraints and Prototype 2

3.1 Design constraints

3.1.1 Identifying the Two Most Important Non-Functional Design Constraints

3.1.1.1 Design for simplicity

Reasoning: Designing for simplicity allows for easier iteration on the prototype by enabling component and subsystem swaps without requiring a complete redesign. Additionally, ensuring the product is easily repairable allows Jan and her caretaker to be more independent, reducing the need for professional maintenance.

3.1.1.2 Design for User Experience

Reasoning: Prioritizing user experience ensures that the device integrates seamlessly into Jan's daily life. It should be easy to operate either independently or with minimal assistance from her caretaker. User-friendly design reduces frustration and enhances usability, making the product more practical and effective.

3.1.2 Changes for Each Design Constraint

3.1.2.1 Design for Simplicity

Current Implementation:

- All components are designed to be easily swapped out without requiring specialized tools.
- The frame and joints utilize finger joints, which allow for quick disassembly and reassembly.

Potential Improvements:

- Further refining the modularity of the design to ensure easy integration of replacement parts.
- Ensuring assembly instructions are clear and simple for non-technical users.

3.1.2.2 Design for User Experience

Current Implementation:

- The device is lightweight, making it easy to move and operate.
- The interface and operation are designed to be intuitive.

Potential Improvements:

- Conducting user testing with Jan to identify potential usability issues.
- Iterating on the design to eliminate friction points in daily use.
- Enhancing ergonomics and accessibility based on feedback.

3.1.3 Proof of Design for Constraints

For this prototype it was tricky to design for these specific constraints. We tried our best to implement simplicity and user experience, however we really need to test our prototype with our client to get more information.

One constraint that we did research and analyze was the power requirement for this design. We researched and found that we needed approximately 20nm of torque to move a human ankle. Therefore, we chose a motor that delivers around 15nm of torque and incorporated a 1:2 gear system that doubles that amount to 30nm. Furthermore, we are using a power cord that will plug into a wall socket in order to deliver enough power for both the Arduino and the motor.

3.1.4 Updated Detailed Design

3.2 The laser-cut blueprint (referenced in the report) shows the use of finger joints, which:

  - Eliminate the need for specialty tools during maintenance or modifications.
  - Allow for quick iteration by enabling easy part replacement.

- We ensured that laser-cut pieces fit tightly together to reduce wear and tear caused by unnecessary movement, thereby improving durability.
- The lightweight structure was chosen based on material selection research, balancing durability with ease of handling. Furthermore, we incorporated suggestions from the design review class which led to us choosing MDF as our material for this prototype.
- We are planning iterative user testing to refine the design and eliminate potential usability flaws.

3.3 Prototype 2

3.3.1 Summarized Client Feedback/Testing Results

From our last prototype, we have not received any new feedback from our client that wasn't already mentioned in our previous deliverables. However, from Deliverable E, we had received new test results from our first prototype. We wanted to test the Load Capacity, Flexion

Angle when Lying or Sitting, the Ergonomic Range of Motion, and the Motor Force against certain expected values, and the results are shown in the table.

Table 3: Target Specifications

Target Specification	Unit	Expected Values	Actual Values
Load Capacity	Kg	6	~8
Flexion Angle when Lying or Sitting	Degrees (°)	40	50
Ergonomic Range of Motion	Degrees (°)	40	50
Motor Force	Newtons Meter (Nm)	10	3

From the results, we can see our first prototype was able to handle a higher load capacity than expected, taking ~8 kg worth of weight. Now that we are creating a laser cut prototype, we expect this value to significantly increase, as the MDF material is much stronger and suited for handling higher loads. The flexion angle and ergonomic range of motion was also slightly higher, moving at a range of 50°. In our laser printed prototype, we are ensuring the range of motion stays the same or can increase through adjustments to the angle of the leg rest. Finally, the motor force was much lower, handling 3 Nm of force. However, we have ordered a special DC motor that uses 12V of energy to supply a horsepower of 60W, much stronger than the 3V motors that were used for the previous prototype, so we are expecting this to increase as well.

3.3.2 Critical Product Assumptions

In Deliverable E, the four critical product assumptions we tested are:

- If the device supports the weight of a human foot (Design for Safety, Reliability).

- The useability of the device when the user is lying or sitting down (Design for Safety, User Experience).
- The ergonomics of the range of motion (Design for Safety, User Experience, Reliability).
- The required force of the motors (Design for Safety, User Experience).

In our second prototype, we are planning to create a laser cut model using more powerful motors controlled by an Arduino. We chose a laser cut model as it provides a better foundation to support a human foot in terms of strength, stability, and wear resistance. The most critical product assumptions we need to test are:

- The ergonomics associated with the foot's natural dorsi/plantar flexion movement (Design for Safety, User Experience).
- The comfortability of the prototype (Design for Safety, User Experience).
- The required force of the motors (Design for Safety, User Experience, Reliability).

3.3.3 Tests to Assess Assumptions

To test the ergonomics associated with the foot's natural dorsi/plantar flexion movement, we will use our own foot in the prototype and mimic the flexion portion of our device. When performing the up and down motion, we will judge whether the flexion follows the natural movement of a dorsi/plantar flexion. This would be to account for the heel drop when plantar flexion occurs and the lateral movement of the heel when dorsi flexion occurs.

In order to test the comfortability of this prototype, we will use our own foot in the prototype and look for key aspects in comfortability. That would be the friction of the material against our skin, the physical hardness relative to our foot, and the overall satisfaction of wearing the device over a long period time. We will also make individual remarks on the feeling of the device in general.

In order to test the required force of the motors, we will benchmark the number on our previous target specification values in Deliverable E. We will then use the new motors and test the strength of them to match our target specifications. We will also develop a separate gear train with the purpose of realigning our motors in a better location. It will not be part of this prototype, but the gear train should provide, if not, more power to the flexion portion of our device. The number will be estimated by the force we believe applied to our foot in relativity with a weighing scale.

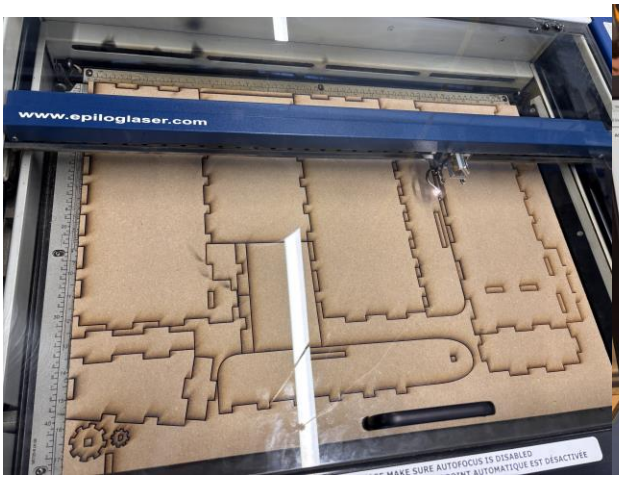
3.3.4 Second Set of Prototypes

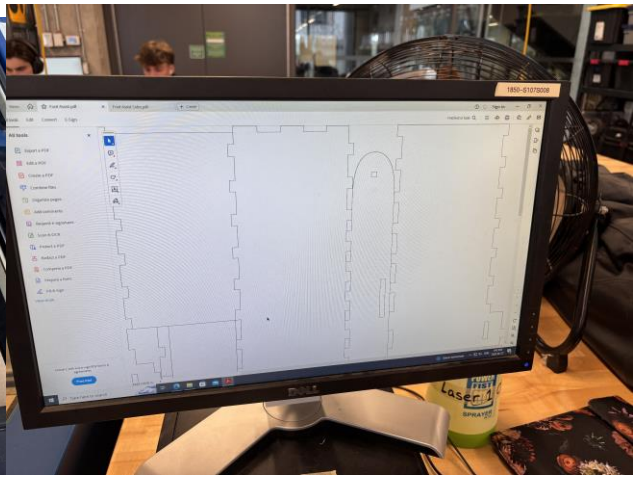
For the second set of prototypes, we have developed a laser cut prototype of our foot flex assist device, along with an Arduino mechanism to power the motor. This will give functionality to the bottom part of our device, which will allow us to flex the foot via console commands from the Arduino console. We have also developed laser cut gears that can help us test the functionality of our gear train, which will be implemented differently in our final prototype.

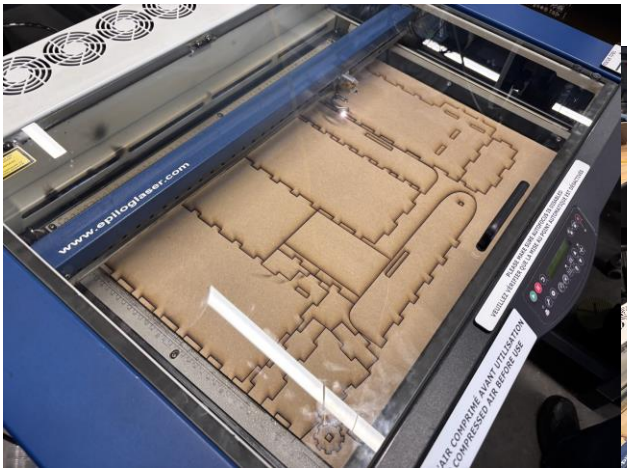
3.3.5 Prototype 2 Documentation

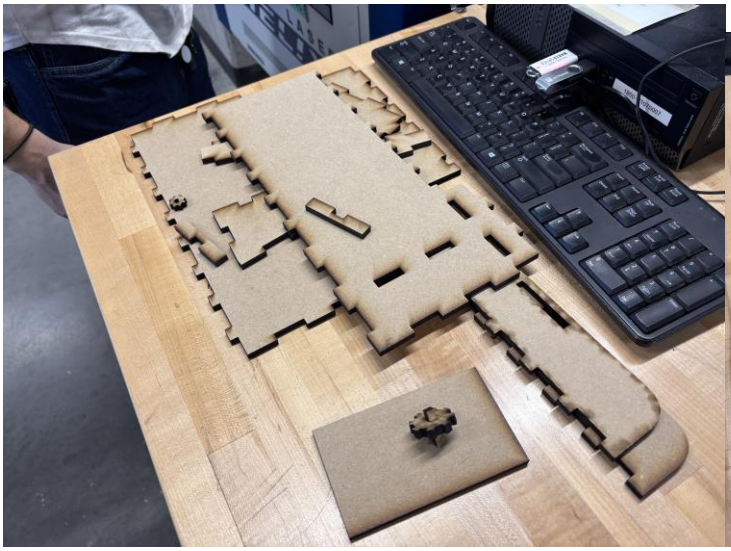
The purpose of our prototype is to test for three target specifications, which is the ergonomics associated with the foot's natural dorsi/plantar flexion movement, the comfortability of the prototype, and the required force of the motors. Despite many of the target specifications being similar to our first prototype, we wanted to retest some old specs with our laser cut prototype rather than the sheet metal prototype we previously had.

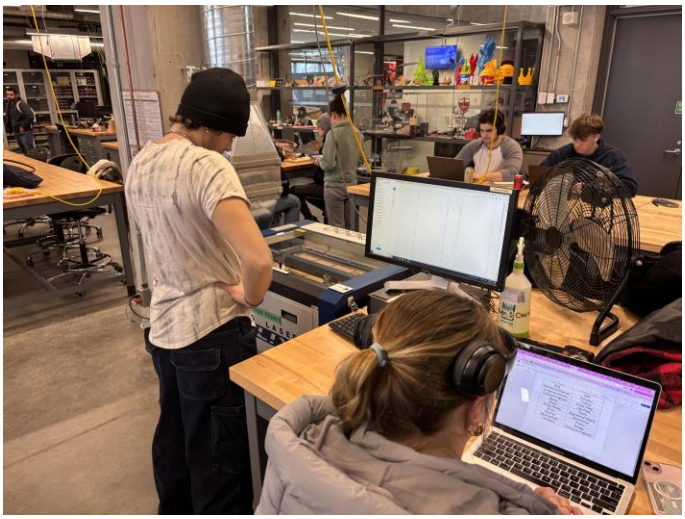
3.3.5.1 Laser Cut Blueprints



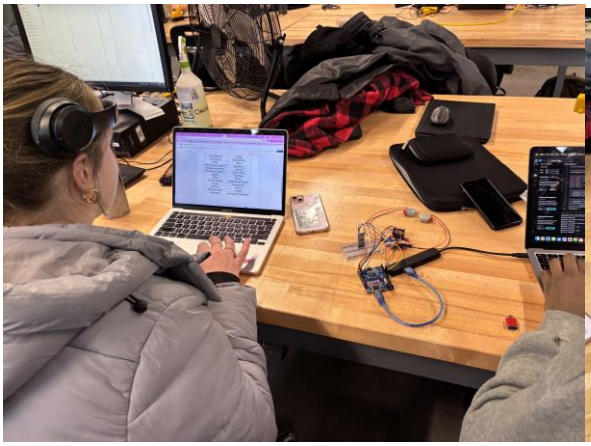


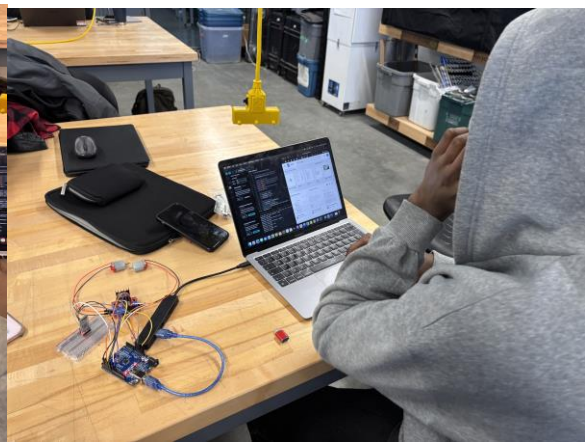


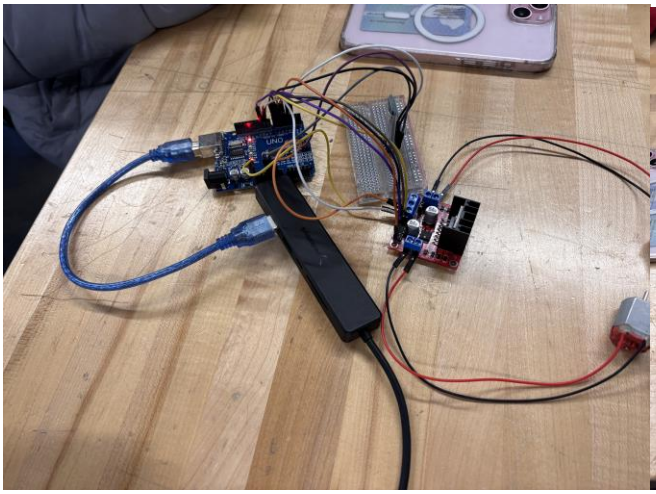


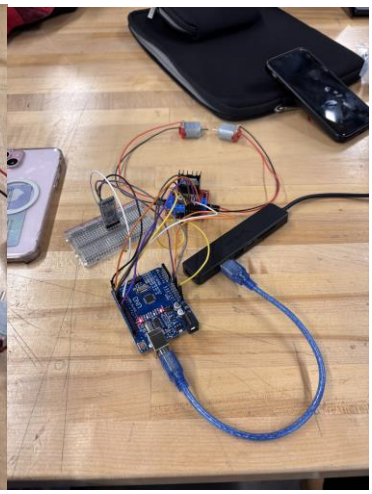


3.3.5.2 Arduino Electronics + Code









3.3.5.3 Assembly

3.3.6 Target Specification Evaluation

We chose to test the ergonomic range of motion because we are making our prototype from a brand-new material, which may influence the range of motion. The material being harder might also affect the natural range of motion in dorsi/plantar flexion, and to account for the heel drop during plantar flexion (which we didn't account for in our first prototype), we had to adjust the prototype to have a base for the heel.

The comfortability would also be affected because we are using MDF which is significantly harder and sturdier. It may lead to uncomfortableness against human skin so we will test the comfortability in the form of blisters created since this was a target specification our client mentioned.

Lastly, the required force of motors will be retested because we want to see how the new motor will work against a completely new prototype. The material, weight and friction will all

play a role in how heavy the motor will turn. We also factor our 1:2 gear ratio that will double the power of the torque measured, so our actual value will be doubled. We also discovered an error in our previous target specifications, in which the expected values and actual values of the torque were much higher than a reasonable torque value. To compensate, we adjusted the expected and actual values in this target specification for the torque.

Table 4: Target Specification Evaluation

Target Specification	Requirement Type	Unit	Expected Values	Actual Values	Verification Method
Ergonomic Range of Motion	Functional	Degrees (°)	50	35	Test
Comfortability	Non-Functional	# of Blisters	0	0	Test
Motor Force	Functional	Newtons Meter (Nm)	0.1	0.4	Analysis

3.3.7 Client Meet 3 Preparation

PowerPoint Link: Powerpoint Link

Questions:

- Ensure that the range of motion is large enough. Ask Jan about the range of motion.
- Allow the client to try on the prototype to ensure its the right size.
- Check if her calf goes all the way to the back of the boot.
- Have her try on the device, despite there not being any padding yet, is it comfortable?
- What's Jan's favourite colour?

3.4 Project plan update

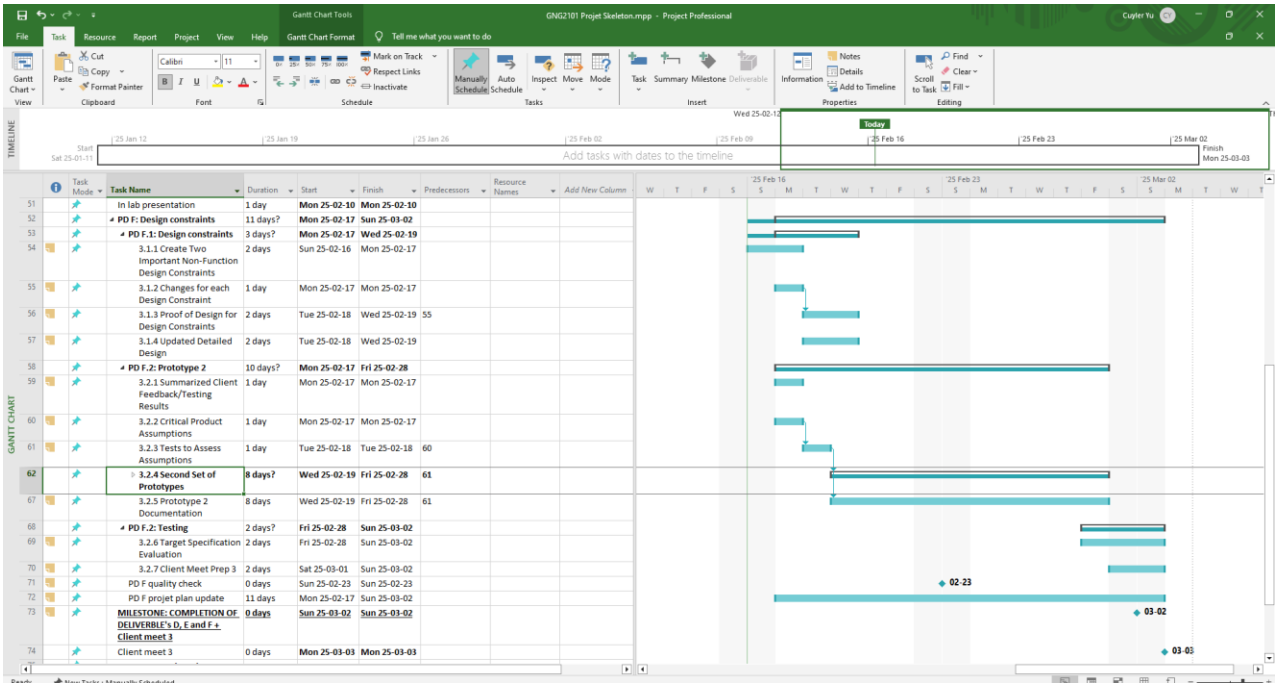


Figure 6: Gantt Chart PD F

4 Economic and IP Considerations

4.1 Economics report

4.1.1 List of Costs

There are many more costs that need to be considered when designing for high- volume manufacturing, because of this we have included a list for both high volume manufacturing and a list for our prototyping costs.

Table 5: List of Prototyping Costs

Cost	Variable or Fixed	Direct or Indirect	Material, Labour, or Overhead
Design Day Poster	Fixed	Direct	Overhead

Building Materials	Variable	Direct	Material
Arduino Parts	Variable	Direct	Material
Matching Clothes	Fixed	Indirect	Overhead

Table 6: List of Costs for Higher Volume – Manufacturing

Cost	Variable or Fixed	Direct or Indirect	Material, Labour, or Overhead
Building Materials	Variable	Direct	Material
Electronic Components	Variable	Direct	Material
Packaging Products	Variable	Direct	Overhead
Advertisement	Fixed	Direct (advertisement for specific product)	Overhead
Transportation	Fixed (within reason)	Direct (transportation of this product)	Overhead
Salaries	Variable (more production = need to higher more employees)	Indirect	Labour

4.1.2 3-Year Income Statement

Table 7: 3 - Year Income Statement

Year	2025	2026	2027
Units Sold	1,560	4,690	6,250
Sales Revenue	$733,200	$2,204,300	$2,937,000
Cost of Goods Sold	$546,000	$1,641,000	$2,187,00
Gross Profit	$187,200	$563,000	$749,000
Operating Expenses	$50,000	$100,000	$150,000
Operating Income	$137,000	$463,000	$599,000

This is the projected income statement of the product over a 3-year period based off the market demand, affordability, competitive pricing, and market share analysis.

4.1.3 NVP Analysis for Breakpoint Even (# of units sold for business to become profitable) [Omon]

To determine the break-even point for the foot flex device, we conducted a Net Present Value (NPV) analysis over a three-year period using projected income and expenses. We assumed a 10% discount rate to calculate the present value of each year's cash flow.

Cash Flow Summary (Operating Income):

- **2025**: $137,000
- **2026**: $463,000
- **2027**: $599,000

NPV Calculation:

Using the NPV formula:

NPV =137,000 / (1.10) ^ 1 + 463,000 / (1.10) ^ 2 + 599,000 / (1.10) ^ 3 NPV =955,920

This means that the present value of the business's net cash flows over three years is approximately **$955,920**.

Break-Even Point:

Given the unit prices and revenue projections, the business becomes profitable when approximately **12,000 units** are sold over the 3-year period. This corresponds with the total operating income exceeding the present value of all expenses, resulting in a positive NPV.

Income cash flow

Time: 0 --------- 1--------- 2 ---------- 3

Cash: 0 ----137,000 -- 463,000 -- 599,000

Expenses cash flow

Time: 0 --------- 1 ----------2 ---------- 3

Cash: 0 ---- 596,000 -- 1,741,000 -- 2,337,000

Expenses ----2025----------2026--------- 2027

4.1.4 Assumptions in Economic Report [Skylar]

Describe and justify all assumptions that you have made in developing your economics report. The assumptions must be factual based on a preliminary market research that you conduct in order to determine the amount of demand in your target market, the expected % of the market that you would own, and the unit price of your product based on a sound pricing strategy.

Important note: we expect you to make many assumptions here. However, each assumption should be identified and justified using information you gathered from various sources. Provide references when using this information.

4.1.4.1 Market Demand

- The target market consists of individuals requiring foot rehabilitation and physical therapy devices, particularly those with limited mobility.
- Preliminary research indicates an increasing demand for at-home rehabilitation solutions due to rising healthcare costs and accessibility concerns. The global home rehabilitation market is projected to reach $280 billion by 2031, growing at a compound annual growth rate (CAGR) of 6.7%. This growth is driven by the rising prevalence of chronic diseases and disabilities, highlighting a significant demand for at-home rehabilitation solutions (ihealthcareanalyst.com).
- Based on comparable product sales data, we assume a total addressable market of 500,000 potential users within the first five years.
- We estimate capturing 2.5% of the market within the first three years, equating to 12,500 units sold.
- Jan's case highlights a gap in the market for an affordable, remote-controlled rehabilitation device that existing competitors do not fully address.

4.1.4.2 Pricing Strategy

- The price of the device is set based on competitor pricing and cost-plus pricing models. Rehabilitation equipment prices vary widely, with devices on Amazon ranging from approximately $30 to over $500, depending on features and brand (amazon.com).
- Automatic devices like ours are often priced between $450 and $650. Our device, incorporating preprogrammed exercises and remote control, is priced at $350 per unit, balancing affordability with product differentiation. This pricing is competitive given the wide pricing spectrum in the market and will appeal to a significant portion of potential users especially those with increased mobility issues.

4.1.4.3 Cost Structure

- Fixed costs include research and development, initial manufacturing setup, and marketing expenses.
- Variable costs include materials (MDF frame, motor, belts, Arduino electronics, memory foam padding), labor, and distribution.
- The estimated cost to manufacture each unit is $120, reflecting the use of cost-effective yet durable components. For example, Arduino boards are available at various price points, with some models priced around $25.50 (store-usa.arduino.cc).
- Gross profit margin is estimated at 52% per unit.

4.1.4.4 Discount Rate

- A discount rate of 10% is assumed based on industry standards for medical and rehabilitation devices. This accounts for risk factors such as market competition, economic fluctuations, and unforeseen costs.

4.2 Intellectual property report

4.2.1 Two Intellectual Properties Related to the Business [Cuyler]

For context, our product is a flex foot assist device used to rehabilitate dorsi/plantar flexion movement in the foot for customers who are paraplegic or require any extensive at home training due to their conditions. Regarding this product criteria, here are two IPs that are related to our product:

1. **Dorsiflex and plantarflex exercise machine [US10434357B2]:**

Invented by Timothy McCarthy and filed on November 27, 2017, the patent is a therapeutic rehabilitation device that utilizes two parallel independent foot pedals on one side of the device, for isolated ankle exercises, and a larger flat board on the other side of the device, large enough for two feet to rest on, for use in active assistance exercises. It can be flipped upside down depending on the mode you would like. To use the device for active assistance rehabilitation, the user places the device on the ground with the two pedals resting on the ground. To use the device for active isolated exercise, the user flips the device over, with the flat board facing the ground, and the two pedals facing upward. The device is fully manual.

This device is very similar to our foot flex assist project in the sense it provides dorsiflex and plantarflex exercises for their customers. The patented device also provides multifunctionality for active assistance rehabilitation, and isolated foot rehabilitation by flipping the device upside

down, which is a component we did not integrate in our device. However, we have our device automatically controlled with preprogrammed exercises, a time setting, and a heating element, something the patent lacks as it depends on the manual strength of the user and is completely mechanized.

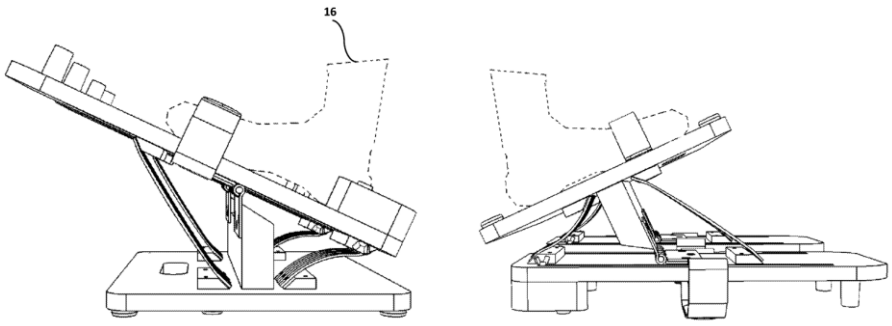


Figure 7: Patent #1 - Dorsiflex and Plantarflex exercise machine

2. **Gait trajectory guiding device of gait rehabilitation device [US20100268129A1]:**

Invented by Seung Hun Park and filed on September 14, 2007, the patent is a gait trajectory guiding device that helps with gait rehabilitation, or the pattern of human walking. It is designed similarly to an exercise machine with a pair of guideway actuating plates that are parallel to each other. Each guideway is moved by the rotation of a corresponding horizontal screw in the longitudinal direction, which also includes footboards that resemble similar trajectories of the movement of human feet/walking. Thus, this device enables a user to conduct gait training in a correct walking motion.

The device resembles our project in the sense it targets the foot and enables rehabilitation training for a client who has weakened/paralyzed foot muscles. However, where our device targets dorsi/plantar flexion movement, the patent targets the natural gait cycle of a human. The patent is also fully manual, meaning the user will have to walk on their own and utilize their own

strength to conduct the training. The device is also quite large as it accommodates a full human body with handlebars for balance, and a body strap to stabilize the person.

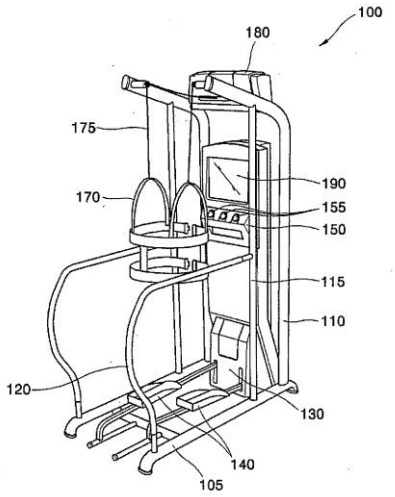


Figure 8**: Patent #2 – Gait trajectory guiding device**

4.2.2 Importance of IPs and the Legal Constraints they place

These intellectual properties are important to know as they place many constraints on our foot flex assist device product. The two patents mentioned above represent products that target rehabilitation therapy regarding the natural movement of the foot, which is the market our product is entering.

We want to scout what existing IPs are already patented and see if our device is too similar. If our device copies what these patents perform, then we may face legal constraints on proceeding further with our product and may be forced to change the design of our product, or the scope of our product. These patents give the inventors the exclusive right to produce, sell, or license the invention for a set period (typically 20 years), and are able to sue those who create a product too

similar to their design. So, it is crucial that we do a patent search to prevent these legal challenges, and we may need to license existing patents in order to have our product legally approved.

However, our product manages to be different enough from these two patents, as our device is an automatically controlled dorsi/plantar flexion device with preprogrammed exercises, and a heating element. The first patent does enable dorsi/plantar flexion therapy but is completely manual and mechanical. The second patent deals with foot therapy, but with gait rehabilitation. Because of these differences, we are able to create our product without legal ramifications and file a patent for our device to be placed on the market.

These two patents don't affect the trademark and copyright of our product since they do not relate to the brand identity or original works of our product (yet).

4.3 Project plan update

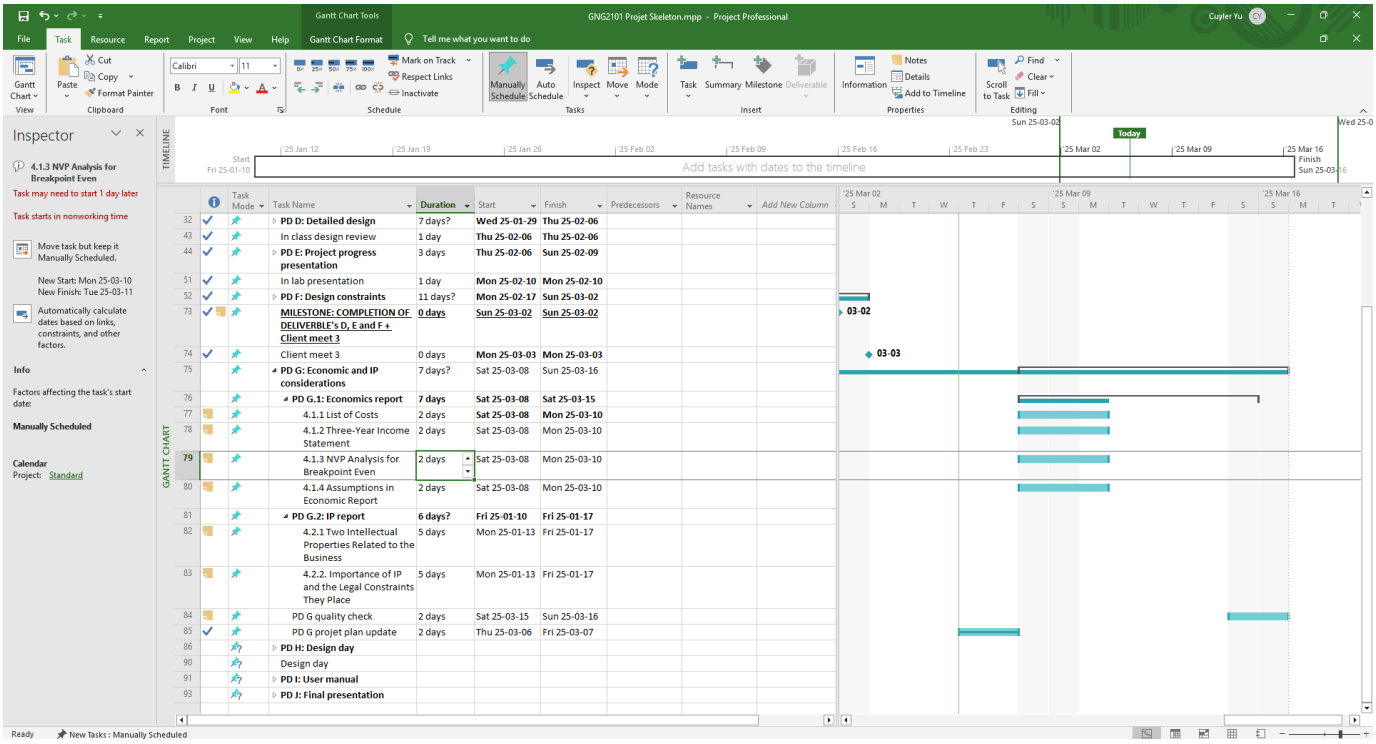


Figure 9: Gantt Chart PD G

5 Design Day Pitch and Final Prototype Evaluation

Design Day Project Presentation Script.docx

6 Video and User Manual

6.1 Video pitch

https://www.youtube.com/watch?v=klUA3DyovfA

6.2 User manual

User_Manual_Template-w23.docx

7 Conclusions

From Deliverables E to I, we have showcased our test plans for prototype 1, prototype 2, our economic and IP considerations and our video and user manual. These deliverables ultimately prepared us for our Design Day Pitch and final prototype evaluation, which is Deliverable H.

8 Bibliography

McCarthy, T. (2017). *US10434357B2 - Dorsiflex and Plantarflex Exercise Machine*. Google Patents. https://patents.google.com/patent/US10434357B2/en?q=%28Dorsiflex%2Bplantarflex%2Bexercise%2Bmachine%29&oq=Dorsiflex%2Band%2Bplantarflex%2Bexercise%2Bmachine. Accessed March 15, 2025.

Park, S. H. (2007). *US20100268129A1 - gait trajectory guiding device of gait rehabilitation device*. Google Patents. https://patents.google.com/patent/US20100268129?oq=reha%2Btechnology%2Bgait%2Brehabilitation. Accessed March 15, 2025.