ENGINEERING

McMaster University

Project Four – Power in Community

The Paint-A-Nator 9001

ENGINEER 1P13 – Integrated Cornerstone Design Projects

Tutorial 03 & 15

Mon-46

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Submitted: April 14th, 2021.

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Academic Integrity Statement

The student is responsible for performing the required work in an honest manner, without plagiarism and cheating. Submitting this work with my name and student number is a statement and understanding that this work is my own and adheres to the Academic Integrity Policy of McMaster University.

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X 

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X *Yara Sharafeldin*

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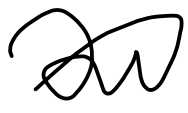
X 

Executive Summary

As a team we were tasked with analyzing and designing a product that would prove helpful to our client and help ease her life through reducing pain and simplifying actions. We created a design that can be used for painting large simple designs. The basis of this design is to convert a joystick movement to movement within a pen plotter attached to the canvas. The classic joystick was then altered to fit to the client's unique circumstance by creating a handle where the client can put their hand in, lacking the necessity to close their fist and fingers around the handle. Support was added to the design in order to add comfort and decrease fatigue in the client's wrist and forearm. Clamps were added to the pen plotter to increase applicability of the pen plotter to a variety of canvas sizes (Figure 23, Section 2 of Appendix A).

Had we been given more resources, time, and money we would have made improvements to our design, for example better motor drivers and longer linear rails/rods for the pen plotter. We would also print a real electronic box or building one from wood (or possibly even a PCB as it provides better cooling and a better opportunity for cable management). Finally, we would us an internal power source as a lighter option could be used provided more resources, time, and money. If we were to go commercial, we would likely provide different options on joystick sizes and linear rails/rod lengths.

Introduction

Background Information

The client is an artist who has been diagnosed with multiple different autoimmune diseases, including chronic lymphedema, which causes swelling under the skin [1] (Figure 2, Section 1 of Appendix A), particularly affecting the client's arms and shoulders. They also have been diagnosed with fibromyalgia, which is a widespread musculoskeletal pain [2] (Figure 3, Section 1 of Appendix A). Another condition the client has been diagnosed with is ankylosing spondylitis, which triggers inflammation in their spine and joints, causing stiffness [3] (Figure 4, Section 1 of Appendix A). These conditions together not only cause pain over their body, but it also has several other side effects, from headaches, fatigue, loss of energy, and to difficulties with concentration. The client has chronic pains that are unpredictable and sporadically changes in levels of pain every day of the week. They have tried forms of art therapy and have practiced and used herbal medicines however, and although they help, these methods of treatment are not permanent solutions. As an artist, more specifically a painter, having these conditions makes painting a difficult task. The client has difficulties painting more finer details as their pains tend to increase, and holding paintbrushes is hard as they occasionally experience difficulties with their fine motor skills (Figure 1, Section 1 of Appendix A).

Refined Problem Statement

Increase the client's ability to complete non detailed strokes while painting or using touchscreens effortlessly through joysticks and large buttons/sliders.

Objectives and Constraints

Our main objectives were easy to prototype, minimizes fatigue on Client, and reliability of product. The constraints relative to our design solution were a weight under 5 pounds (10 if client is sleeved), and 3 ½ inches width of the client's hand.

Existing Ideas and Solutions

Pen plotters have been a thing since around the 1980's but the Paint-A-Nator 9001 allows its users to paint with limited physical abilities. The rest of these plotters were not usually used for painting and when they were, the controls did not apply for people with disabilities, so we took it upon ourselves and modified one to fit our needs. When searching online for 3D printed pen plotter you will find tons on Thingiverse, however, due to our tight time schedule we used an open-source pen plotter[4].

Conceptual Design

Ideation

We brainstormed multiple different approaches on possible solution options and through discussion as a team leaned towards a design with an effortless input and an output, pen plotter, which would do the painting. Once we had our refined problem statement, we concluded a modified pen plotter would be the best solution for our design. Our initial design from all 4 members included pen plotter but the main differences where the control interface, we had multiple ideas from joysticks vs slider to shoulder support vs wrist support. After deliberation and support from science students we decided on a wrist supporting joystick and 2 button controllers.

Design Alternatives and Decision Matrix

As you can see in Figure 13 in Section 2, we had alternative designs in joystick or possibly even using a touch screen tablet (Figure 14, Section 2). In the end we decided that a stereotypical joystick design would be supreme with a couple alterations to increase the ergonomics of the design to decrease pain and discomfort in the client. A large alteration included a change in handle as a stereotypical handle would require the client to

grip a bulb whereas our design allows them to insert their hand as it does not require them to close their fist, better fitting it to the client.

Design Evaluation

Some comments made during our first design review meeting were to consider when the client wants to change paint colours, how easy the design is to fix when faced with malfunctions, are there any time delays or such in processing time, and variation of intended texture of paint. Motors and buttons were added to turn the paintbrush to account for the texture variation and to allow for easy access to change colour or add more paint, the design also allows for paintbrush change. Certain materials were used to minimize time delay. The design prototype was made with simple components to add simplification for any needed correction due to malfunctions.

During the second design review meeting the large concept that was questioned was whether this design would cause a disconnect between the client and painting. We asked the client what is important to them when painting, they answered that they did not particularly enjoy painting backgrounds or repainting canvases. This is what our design is intended for, therefore we did not make alterations due to this. Although a comment from the client was that closing their fists result in pain and fatigue, and that wrist and forearm support is preferred. Due to this we altered the handle design, our design already allows for movement of the joystick allowing the client to easily use the design with support of the wrist and/or forearm (Figure 17. Section 2 of Appendix A).

Final Proposed Design

Our final design is a 4 axis CNC painting machine, controlled by a custom control board with an ergonomic joystick and 2 arcade buttons.

The Basics of the Design:

This design works using 2 stepper motors with belts for the x and y axes, the z and rotation axes are each controlled by servo motors. The x axis uses a linear rail to constrain the movement while the y axis uses 2 pairs of linear rods and bearings. The z axis is constrained by a linear bearing and rod. The rotational axis is constrained since it is attached directly onto the SG-9 servo, which in turn is glued down the end of the y axis. Each 4 directions of the x and y axis have a limit switch which stops movement if actuated. To control all these axes there is a control box connected to the machine with a 2.5-meter-long cable which includes an 8-axis joystick and 2 arcade buttons. The main body and controller were modelled in Autodesk Inventor in two different assemblies (Figure 21 & 22. Section 2 of Appendix A).

The Electronics:

All these Inputs and Outputs are wired up to the Raspberry Pi Foundation's new Raspberry Pi Pico microcontroller based off the RP2040 microcontroller according to the wiring diagram shown below. (Figure 18. Section 2 of Appendix A)

The motors are driven off 12 volts using the L298D motor driver using 4 PWM signals from the Pico each (These signals are PWM and not digital as they are micro stepped). The servos are driven from the Pico using the on chip PWM generator with a minimum pulse of 500ms and maximum pulse of 2250ms. The Pico only accepts 3.0-5.5v so we included a 12v to 5v buck convertor to power it. Lastly the power supply is rated for 12v 6 amp but using a multimeter we concluded it draws a max of just under 4 amps leading to a max power draw of around 48 Watts.

The Code:

The RP2040 Firmware is coded in Circuitpython, an Adafruit industries fork of python focused on microcontrollers. The external libraries used are the adafruit_motor library used for controlling the 4 included motors (2 stepper and 2 servos). The motors, limit switches, joystick, and arcade buttons are first initialized. Then a variable called "angle" is initialized to keep track of the servo motor's current angle. The rotation servo is then reset to parallel with the painting surface before the main loop is ran. For the main loop we check if each input is "True" and the according limit is not reached if so, turn the respective motor. Pseudocode for this program is included in an image below **(**Figure 19. Section 2 of Appendix A)

Using the Device

Our device is used by attaching it your easel on top of your canvas using clamps. You then insert and screw in your paintbrush. Then flick the power switch to turn on the device. As the servo defaults to parallel with the painting surface you easily add paint onto your paintbrush. Using the controller, you then turn the servo onto the painting then after, put your hand within the joystick and paint to your hearts content.

Final Drawings

The final engineering drawings have a more detailed description of the assemblies of the controller and device (Figure 24, 25. Section 3 of Appendix A).

These drawing are slightly different than the real physical product due to time constraints. The clamps we used for our physical product was a set of household clamps unlike the 3D printed ones on the assembly. Lastly the body of the controller was different due to budget and time constraints as we have time to print a custom box or money to buy one.

Objectives/Constraints Met

Objectives: Easy to prototype, Minimizes Fatigue on Client, and Reliability of Product

We believe we met almost all our objectives to a high degree of consistency, our product took us less than three weeks to physically prototype, our product allows the client to put energy into our product instead of painting and works reliably throughout the day most of the time. The metrics we used for easy to prototype are total prototyping time which as stated was 3 weeks, which we understood as completing the objective. The metric we used for minimizes fatigue on client is effort it takes to completely cover one whole canvas in one colour, after testing it on Ariel and 3 of his family members they stated an average of 80% less energy which we understood as completing the objective. For reliability of the product Ariel tested the product for about 6 hours with a three thirty-minute breaks in between and it never failed, which we understood as completing the objective. The limitations of our metrics where a small sample size for fatigue that did not even include our target client, and we only had one person test it for 6 hours all in one day. These limitations mean our metrics are pretty accurate but could be improved with mainly a larger sample size.

Constraints: Weight Under 5 pounds (10 if client is sleeved), 3 ½ inches width of the client's hand

We also believe we met all the design constraints as although there were a variety of constraints provided, these were the only two relevant to our solution. As the Joystick and Pen-Plotter each are each within the weight constraint of the client to provide the independence the client asked for. The joystick obliges by the constraint of the client's hand for them to be capable of inserting their hand for usage without pain.

Bill of Materials

Name	Specification	Price	Link
3D Printing Filament	1.75mm 1KG	$19.95	Filaments.ca
Power Supply	12V 6A	$23.99	Amazon.ca
Linear Rod	8mm diameter, 400mm long	$20.53	Amazon.ca

Linear Rod	8mm diameter, 500mm long	$30.89	Amazon.ca
Motor Driver	2 Pack L298N	$13.99	Amazon.ca
2x SIMAX3D Stepper Motors	NEMA 17	$37.98	Amazon.ca
GT2 Smooth Timing Pulley	3mm Bore	$11.99	Amazon.ca
Linear Rail	300mm	$32.29	Amazon.ca
Microswitch	10 Pcs	$11.99	Amazon.ca
SG90 Servos	5 Pcs	$19.99	Amazon.ca
GT2 Set	Timing Belt, 4 Teeth Pulleys	$15.99	Amazon.ca
Linear Bearings	25mm Long	$20.29	Amazon.ca
Linear Bearings	45mm Long	$16.99	Amazon.ca
Lock Nut	Assorted (M3-M12)	$15.99	Amazon.ca
Fastener Kit	Assorted (M2-M5)	$34.89	Amazon.ca
Scrap MDF	5/8” Thick	$5.00	On Hand
Total Price		**$332.65**	

Constructing the Product

We completed a physical design of our product as can be seen in Figure 23, in Section 2 of Appendix A. For the pen plotter we used an open source (CC attribution 4.0 International (CC BY 4.0)) design for the x, y and z axes with permission and excitement [4]. This design was meant for drawing parallel to the ground, so we needed to modify to work on an easel. The modified sections of the pen plotter include the pen slider, addition of the rotation axis, and modified z axis. We also constructed a controller and electronics box. The construction took about 2.5 weeks including the about 3 days spent 3D printing. We used 3D printing for the main parts as it was very cheap and accessible as a group member already owned a 3D Printer. If we had the resources, we might have CNC milled the parts in 6061 aluminium due to the increased rigidity without a massive weight increase. For linear rails vs rods, we used rails for the x axis as it was cheaper to buy one 300mm rail than 2 300 mm linear rods, on the y axis we attempted to implement linear rails but the rods where much simpler. The electronics box was built from a waste cardboard box due to budget and time restriction, building a wooden box

or 3D printing one would have been the right choice, but we ran out of both money and resources. For the microcontroller, the Raspberry Pi Pico only costs $4 compared to the original design's $20-$40 Arduino Uno. Additionally, we removed the z axis from our machine as it did not benefit us and the rotational axis provided us with virtual z axis functionality. Lastly the joystick handle was 3D printed but with more time and resources we would have but a layer of cloth onto to easy the client in her everyday use.

Conclusion

Looking Ahead

While we believe our design is great, we also believe there are many areas for improvement that would just be a result of greater funding. In terms of time, we could have designed and printed or built from wood a real electronics box or even a PCB for better cooling and cable management. Currently the power supply is external which does reduce weight but could create a bad situation if it fell. In the money department we would have spent it on motor drivers and longer linear rails/rods. The motors produce a whine due to the L298N stepper drivers we used, they are not silent micro stepping drivers and could be easily replaced if we put in a greater investment into the project. Currently the max painting surface is around 300mm x 400mm, but this is just constrained due to the limited money we could spend on smaller linear rails/rods. Other than those small improvements we believe our prototype is still fully functional and completes its job well.

Looking Back

Looking back upon the project we believe that our group did a great job. The fact that we completed a physical working prototype that looks almost identical to many of our concept sketches is a representation of our design process. This project was a great opportunity to display all the skills we have learned throughout this school year and showcase our abilities. Through this project we have learned the importance of collaboration as every team member has different qualities, experiences, and mindsets they can add to optimize our design. Our design process worked well as we split up the work evenly and allowed each team member to excel in their own separate sections. Ariel had prior maker experience, so he took on the task of making the design, Tisuka had prior video editing and CAD experience so he took on the task of editing our video and completing the joystick handle CAD, Milica had prior experience with CAD and writing so she helped lead the milestones and contributed to the CAD, Yara had prior experience with CAD and writing so gave input in the process and contributed to the pre-recorded video. Overall, we believe our group did an excellent job on this project and hope to make something even cooler in the future courses.

Project Contribution

Name, MacID	**Contributions**
Ariel Wolle, wollea	Coded Firmware for Microcontroller Designed parts of Final CAD Physically built Projects Completed multiple parts of final report Wrote part of script for video Lead presentations
Milica Nenadovic, nenadovm	Strongly Participant in completing Milestones Participating in completion of final report and Organization Wrote part of script for video
W. Tisuka Perera, pererw2	Designed Joystick Device Model in Autodesk Inventor (initial, refined) Completed multiple parts of the final report Wrote part of script for the video Created and edited Pitch Video for Final Presentation
Yara Sharafeldin	Checked the reference's credibility Participated in video

List of Sources (IEEE Format)

1. H. Brorson, A. Warren, L. J. Borud, S. A. Slavin, “Lymphedema: A Comprehensive Review,” Annals of plastic surgery, Oct-2007. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/17901744/. [Accessed: 12-Apr-2021].

2. D. J. Clauw, “Fibromyalgia: an overview,” The American journal of medicine, 2009. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/19962494/. [Accessed: 12-Apr-2021].

3. E.B. Gouveia, D. Elmann, M.S. Morales, “Ankylosing spondylitis and uveitis: overview,” Rev Bras Reumatol, Oct-2012. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/23090374/. [Accessed: 12-Apr-2021].

4. D. I. Y. Machines, “Easy 3D Printable CNC Drawing Machine.” [Online]. Available: https://www.thingiverse.com/thing:4537916. [Accessed: 14-Apr-2021].

Appendix A: Section 1-3

Section 1

Client Meeting Notes:

- Client was a worked in reproductive health in her early 20s, midwife for 15 years
- Client got into a car accident, which resulted in injury
- Client is an activist and wants to continue with these activities
- Client has multiple auto-immune diseases/disorders and other diseases
  - Breast Cancer
    - Lymphedema (Breast Cancer Surgery) increases chance of swelling and infection.
    - Still undergoing chemotherapy
  - Fibromyalgia
  - Spondylarthritis Arthritis
    - Difficulty when having to bend around waste
  - Receiving and IV would put her at higher risk, likely lead to sickness
- Client enjoys Painting, Meditation, Brazilian Jujitsu, Gardening, Sewing, Knitting, Quilting, and playing with her kids (9 and 11 years old)
- Client uses Painting as an outlet and a means to communicate
- Client uses Meditation to provide Peace and Calmness
- Client struggles or/and has had to adapt many of the activities listed above due to pain and a lack of daily reliability in mobility and control of her body
  - Muscle spasms and struggle with intricacies
    - A large struggle when painting, sewing, knitting or quilting
      - What if there was a way to secure a paint brush "in" the clients hand without her having to use her hand
  - Struggle holding small brushes
    - Client's current solution was buying softer and wider brushes to help with a minimize struggle
  - Difficulty with lifting objects
    - Household chores for example emptying the dishwasher, or cleaning up toys her children leave on the floor are very strenuous and painful (sometimes impossible)
    - Certain movements and poses in Meditation and Jujitsu require reliability of body weight on arms
    - Needs help when gardening, in particular planting
  - Client struggles with sitting
    - Can't always sit and paint on canvas upright
- Client uses gardening for Herbalism
  - Grows herbal remedies and medicine
- Client enjoys reusing materials in sculptures.
- Client wants "exoskeleton."
- Client enjoys Acrylic and Oil (Cold Wax) Painting specifically
- Client's largest Challenge is the unpredictability with her body daily
  - Some days are better than others ("One Day at a Time")
  - Client struggles with following through full tasks as an increase of struggle with spontaneously occur
- Client can struggle from "Brain Fog" due to severity of pain
- Client would like gentle support of her body and wants to experience the compassion in engineering
- Due to COVID client lacks a community
- Client enjoys using her hands but struggles with control and hand eye coordination
  - Can lead to danger
- Client has a lot of braces and such that are very uncomfortable to wear
  - Gauntlet Compression Sleeve
  - Compression Vest for Torso
  - SI Brace/Belt (Walking)

Figure 1. Milestone 1 - Client Meeting Notes

Medical Documents:

Lymphedema: a comprehensive review

Anne G Warren [1], Håkan Brorson, Loren J Borud, Sumner A Slavin

Affiliations + expand

PMID: 17901744 DOI: 10.1097/01.sap.0000257149.42922.7e

Abstract

Background: Lymphedema is a chronic, debilitating condition that has traditionally been seen as refractory or incurable. Recent years have brought new advances in the study of lymphedema pathophysiology, as well as diagnostic and therapeutic tools that are changing this perspective.

Objective: To provide a systematic approach to evaluating and managing patients with lymphedema.

Methods: We performed MEDLINE searches of the English-language literature (1966 to March 2006) using the terms lymphedema, breast cancer-associated lymphedema, lymphatic complications, lymphatic imaging, decongestive therapy, and surgical treatment of lymphedema. Relevant bibliographies and International Society of Lymphology guidelines were also reviewed.

Results: In the United States, the populations primarily affected by lymphedema are patients undergoing treatment of malignancy, particularly women treated for breast cancer. A thorough evaluation of patients presenting with extremity swelling should include identification of prior surgical or radiation therapy for malignancy, as well as documentation of other risk factors for lymphedema, such as prior trauma to or infection of the affected limb. Physical examination should focus on differentiating signs of lymphedema from other causes of systemic or localized swelling. Lymphatic dysfunction can be visualized through lymphoscintigraphy; the diagnosis of lymphedema can also be confirmed through other imaging modalities, including CT or MRI. The mainstay of therapy in diagnosed cases of lymphedema involves compression garment use, as well as intensive bandaging and lymphatic massage. For patients who are unresponsive to conservative therapy, several surgical options with varied proven efficacies have been used in appropriate candidates, including excisional approaches, microsurgical lymphatic anastomoses, and circumferential suction-assisted lipectomy, an approach that has shown promise for long-term relief of symptoms.

Conclusions: The diagnosis of lymphedema requires careful attention to patient risk factors and specific findings on physical examination. Noninvasive diagnostic tools and lymphatic imaging can be helpful to confirm the diagnosis of lymphedema or to address a challenging clinical presentation. Initial treatment with decongestive lymphatic therapy can provide significant improvement in patient symptoms and volume reduction of edematous extremities. Selected patients who are unresponsive to conservative therapy can achieve similar outcomes with surgical intervention, most promisingly suction-assisted lipectomy.

Figure 2. Lymphedema: a comprehensive review

Fibromyalgia: an overview

Daniel J Clauw [1]

Affiliations + expand

PMID: 19962494 DOI: 10.1016/j.amjmed.2009.09.006

Abstract

Fibromyalgia is the diagnosis given to individuals with chronic widespread musculoskeletal pain for which no alternative cause, such as tissue inflammation or damage, can be identified. Fibromyalgia is now believed to be, at least in part, a disorder of central pain processing that produces heightened responses to painful stimuli (hyperalgesia) and painful responses to nonpainful stimuli (allodynia). Aberrations in central pain processing may also be partly responsible for symptoms experienced in several chronic pain disorders that coaggregate with fibromyalgia, which is itself a product of genetic and environmental factors. Thus, aberrational central pain processing is implicated in irritable bowel syndrome, temporomandibular disorder, chronic low back pain, and certain other chronic pain disorders. Fibromyalgia and related disorders appear to reflect deficiencies in serotonergic and noradrenergic, but not opioidergic, transmission in the central nervous system. The heightened state of pain transmission may also be owing to increases in pronociceptive neurotransmitters such as glutamate and substance P. In some cases, psychological and behavioral factors are also in play. Although the overlapping symptomatology between fibromyalgia and related disorders may present diagnostic challenges, proper examination and observation can help clinicians make an accurate diagnosis. In recent years, the vastly improved understanding of the mechanism underlying fibromyalgia and the related spectrum of diseases has fostered rapid advances in the therapy of these chronic pain disorders by both pharmacologic and nonpharmacologic interventions.

Figure 3. Fibromyalgia: an overview

Ankylosing spondylitis and uveitis: overview

[Article in English, Portuguese]
Enéias Bezerra Gouveia [1], Dório Elmann, Maira Saad de Ávila Morales

Affiliations + expand

PMID: 23090374

Abstract

The present article reviews the epidemiology, pathogenesis, clinical features, diagnosis, and treatment of ankylosing spondylitis and its association with ocular changes. The authors used the PubMed (MEDLINE), LILACS, and Ophthalmology Library databases. Ankylosing spondylitis is a chronic inflammatory disease that usually affects the axial skeleton and can progress to stiffness and progressive functional limitation. Ankylosing spondylitis usually begins around the second to third decade of life, preferentially in HLA-B27-positive white males. Its etiology and pathogenesis are not completely understood, and its diagnosis is difficult. Clinical control and treatment are frequently satisfactory. Acute anterior uveíte is the most common extra-articular manifestation, occurring in 20%-30% of the patients with ankylosing spondylitis. Approximately half of the acute anterior uveíte cases are associated with the presence of the HLA-B27 antigen. It can be the first manifestation of an undiagnosed rheumatic disease, usually having a good prognosis and appropriate response to treatment. In conclusion, for better assessment and treatment of patients with uveitis, ophthalmologists and rheumatologists should work together.

Figure 4. Ankylosing spondylitis and uveitis: overview

How/Why Ladder:

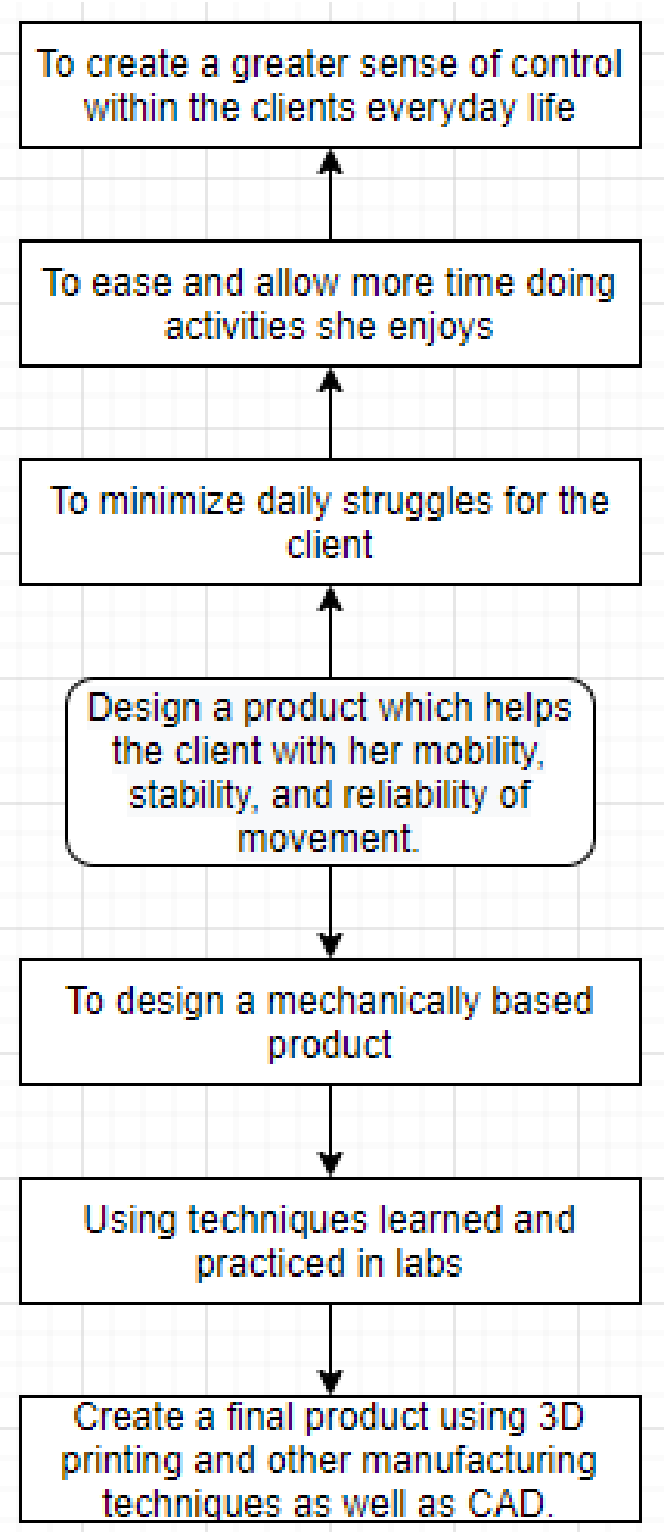


Figure 5. Milestone 1 - How/ Why Ladder

Commercial Products:

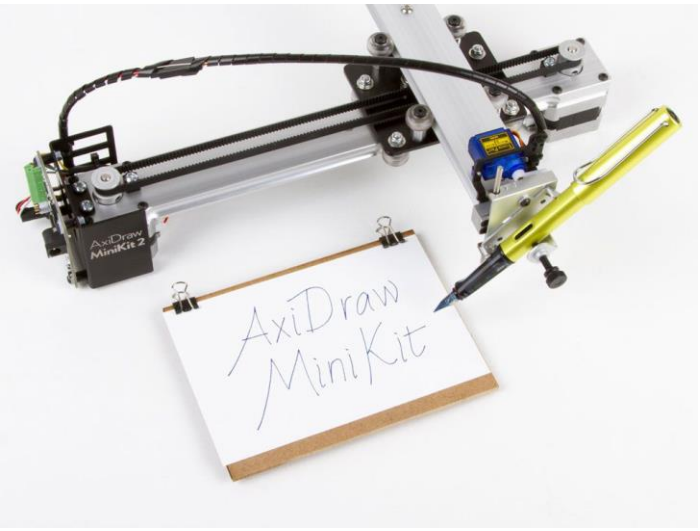


Figure 6. Commercial Product: AxiDraw MiniKit 2 – Compact Pen Plotter DIY-Kit

Section 2

Morph Chart:

Functions	Means			
	1	2	3	4
Accessible controls	Joystick	Large Buttons	Sliders	Motion Control
Accurate Positioning	Steppers	Servos	Homing Switches	…
Response Time	Direct connection	Wireless Connection	Faster Microcontroller	…
Applicable to multiple canvas/tablet sizes	Extensions	Multiple means of grip	…	…
Ease in mounting	Canvas Clamps	…	…	…

Table 1. Milestone 2 - Morphological Chart

Initial Sketches:

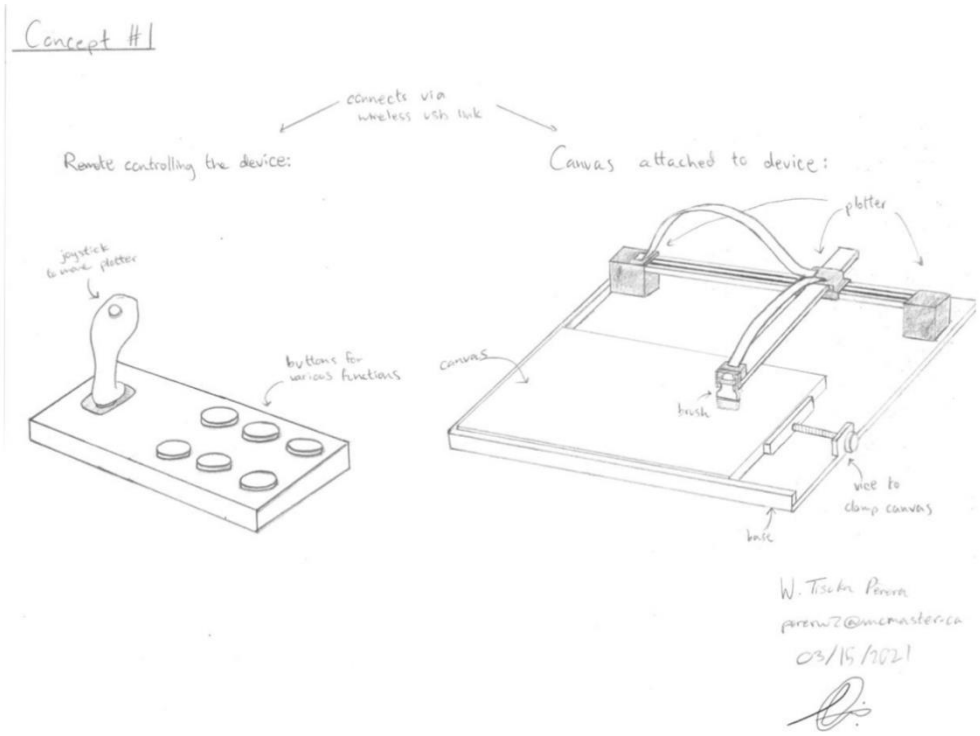


Figure 7. Milestone 2 - W. Tisuka's Initial Sketch of Joystick and Pen Plotter

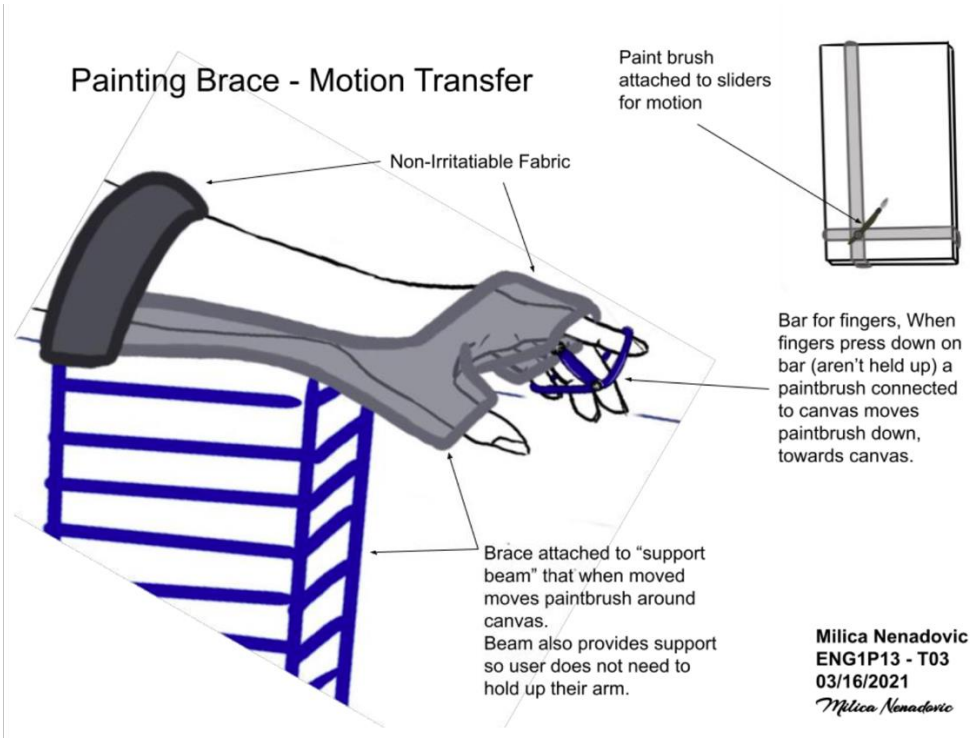


Figure 8. Milestone 2 - Milica's Initial Sketch of Arm-Brace Joystick and Pen Plotter

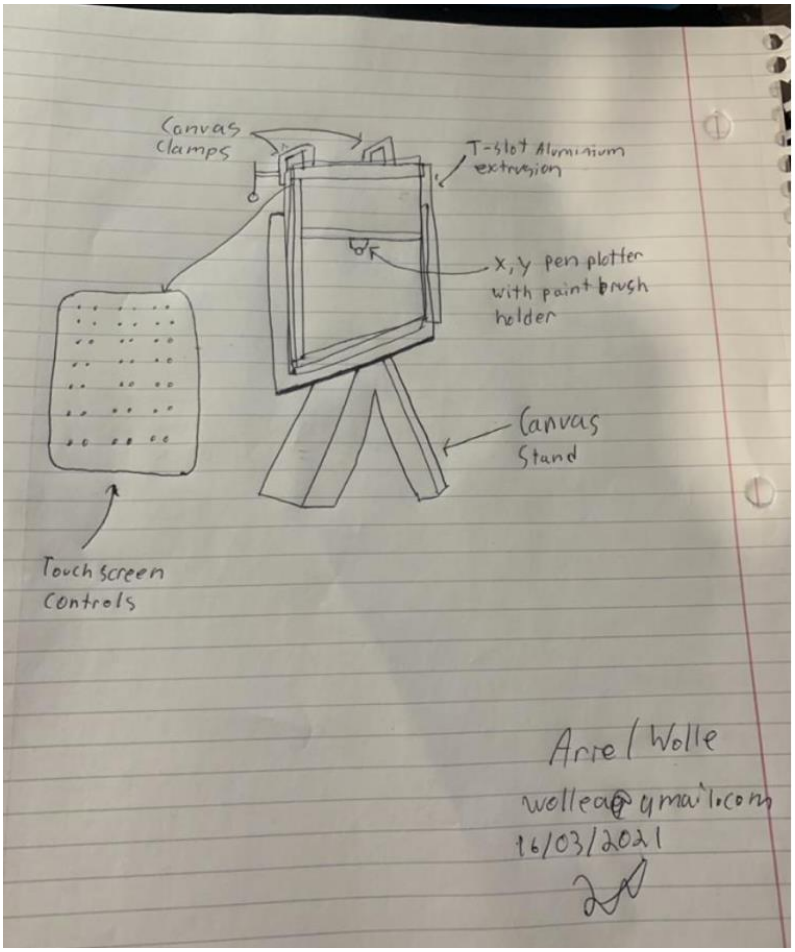


Figure 9. Milestone 2 - Ariel's Initial Sketch of Touchscreen and Pen Plotter

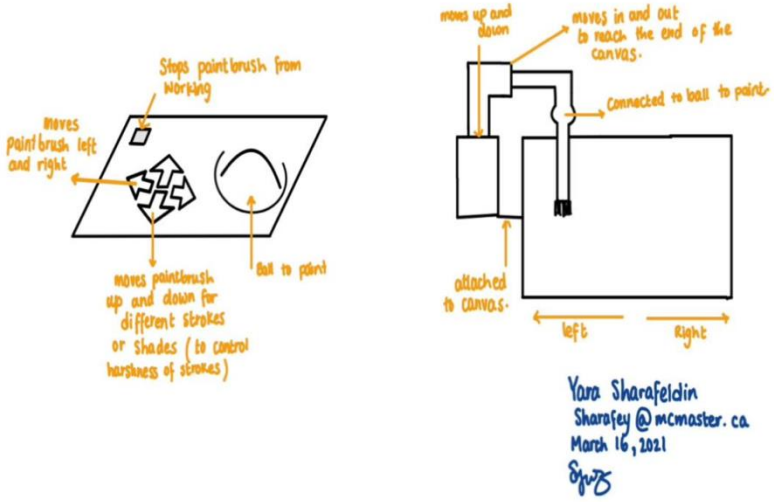


Figure 10. Milestone 2 - Yara's Initial Sketch of Ball-mouse Controller and Pen Plotter

Initial Prototypes:

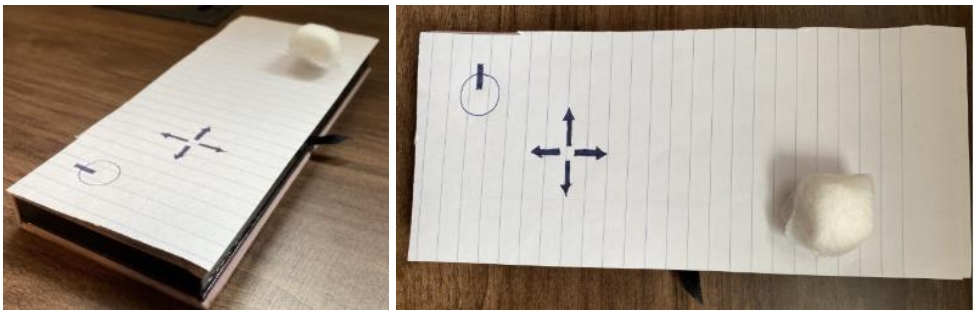


Figure 11. Milestone 3 – Yara's Prototype

Figure 12. Milestone 3 – W. Tisuka's Prototype

Figure 13. Milestone 3 – Milica's Prototype

Figure 14. Milestone 3 – Ariel's Prototype

Decision Matrix:

Design (w/ Pen Plotter)	*Durability*	*Easy to Fix*	*Ease in Usage*	*Provides the feeling of Painting*	*Lack of Pain associated with Use*	**Rank**
Rolling Joystick	*3*	*2*	*4*	*4*	*3*	*4*
Joystick with Buttons	*2*	*1*	*1*	*2*	*1*	*1*
Arm Joystick	*4*	*3*	*2*	*2*	*4*	*3*
Touch Screen Tablet	*1*	*4*	*3*	*1*	*2*	*2*

Table 2. Milestone 3 – Decision Matrix

Design Review Notes:

- *Good job* - *Working Prototype is impressive*
- *Interesting and Creative* - *Bluetooth or Plugged in?* - *Adjustable for size?* - *Change colours.* - *Account for how light client is painting (Yes)* - *Time Delay? (Real time with Max speed restriction))* - *How easy is it to fix? (Easy on a good day, will need help on a bad day)* - *Scaled down is expectable.*

Figure 15. Milestone 3 – Design Review Notes/Feedback

- *How would you optimise the design?* - *Does this cause a disconnect between the client and painting?*
- *Does this cause a disconnect between the client and painting?* - *Texture and watercolours (Pressure?)*
- *Would like support in wrist and forearm.* - *Grip might be painful.*

Figure 16. Milestone 4 – Design Review Notes/Feedback

Prototype Milestone 4:

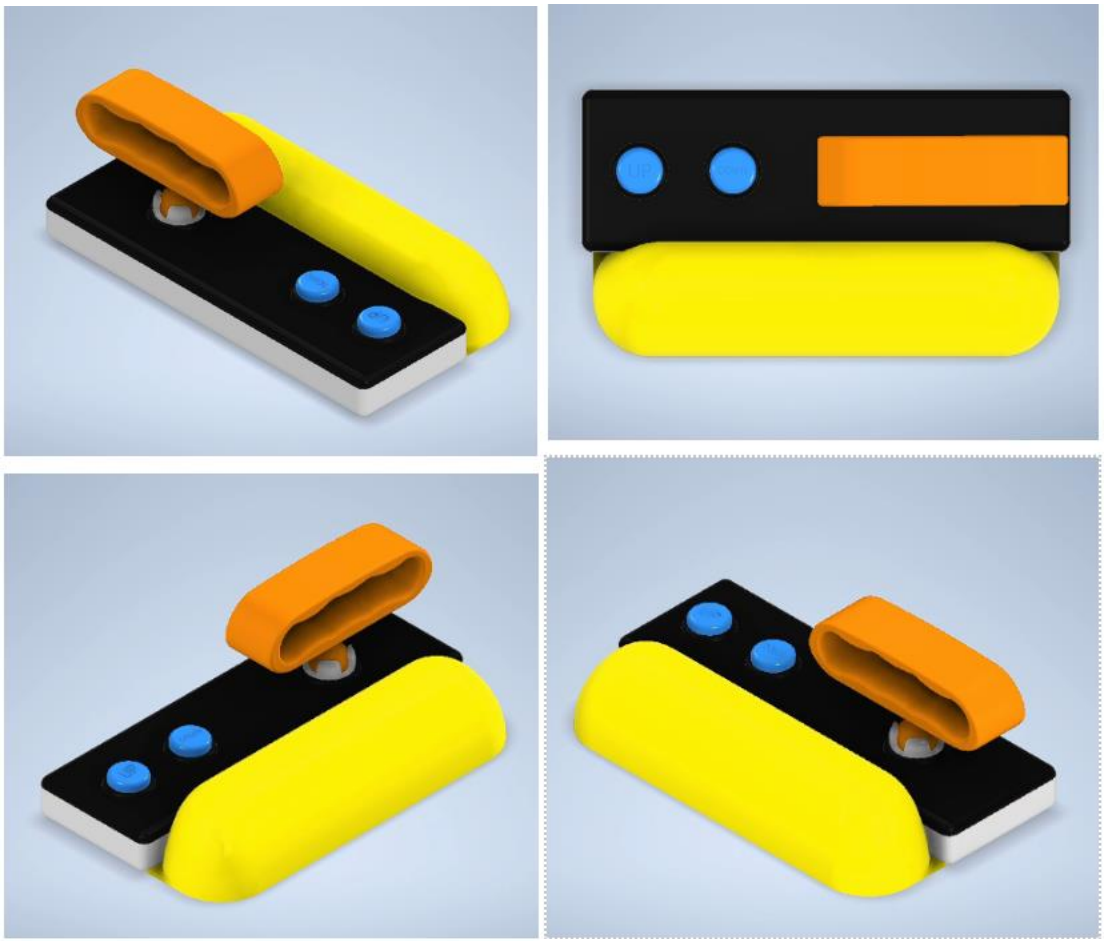


Figure 17. Milestone 4 – Refined Joystick CAD Model

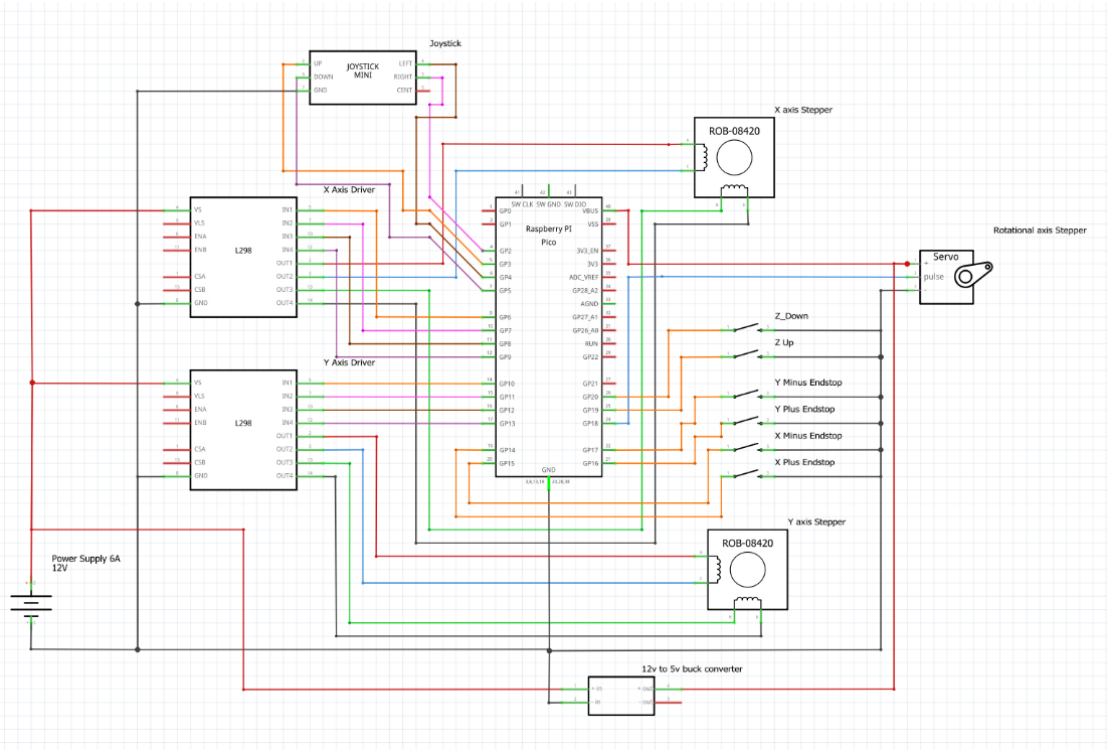


Figure 18. Wiring Diagram for Pen Plotter

```
Import microcontroller libraries
Import adafruit_motor libraries
Initialize joystick Pins
Initialize rotation button Pins
Initialize rotation servo motor
Initialize x axis stepper motor
Initialize y axis stepper motor
Initialize limit switches
Initialize variable to keep track of current angle of the rotation servo
Reset servo motor to parallel with the painting surface
Start main loop
    Wait a small amount of time to allow motors to spin at proper speed
    If joystick is moved to the right and x axis is not at max right position
        Turn x axis motor a quarter of a step in the forward direction
    If joystick is moved to the left and x axis is not at max left position
        Turn x axis motor a quarter of a step in the backward direction
    If joystick is moved up and y axis is not at highest position
        Turn y axis motor a quarter of a step in the forward direction
    If joystick is moved down and y axis is not at lowest position
        Turn y axis motor a quarter of a step in the backward direction
    If both rotation buttons are not pressed at the same time
        If the counter-clockwise rotation button is pressed
            If the angle is not at the max counter-clockwise position
                Rotate servo in the counter-clockwise direction 0.2 degrees
        If the clockwise rotation button is pressed
            If the angle is not at the max clockwise position
                Rotate servo in the clockwise direction 0.2 degrees
    Return to start of the loop
```

Figure 19. Pseudocode for Pen Plotter

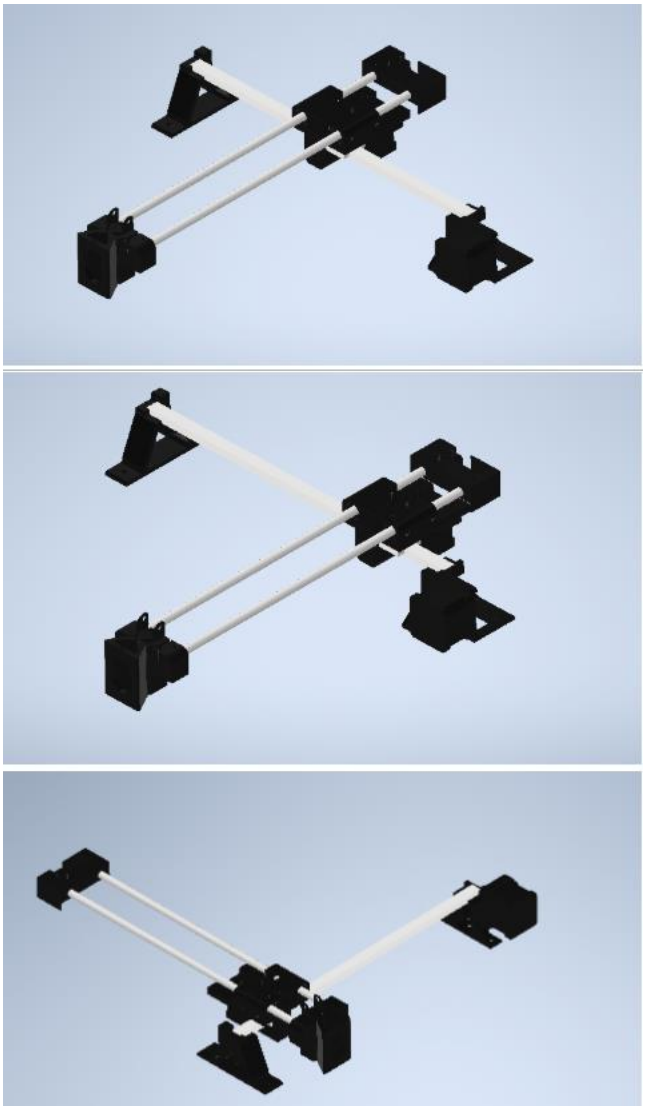


Figure 20. Milestone 4 – Pen Plotter CAD Model

Final Prototype:

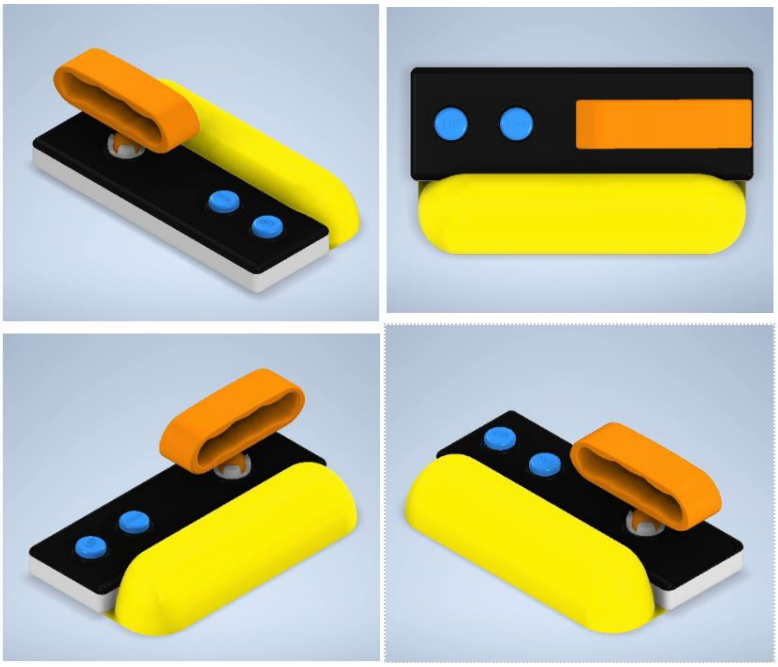


Figure 21. Milestone 4 – Refined Joystick CAD Model

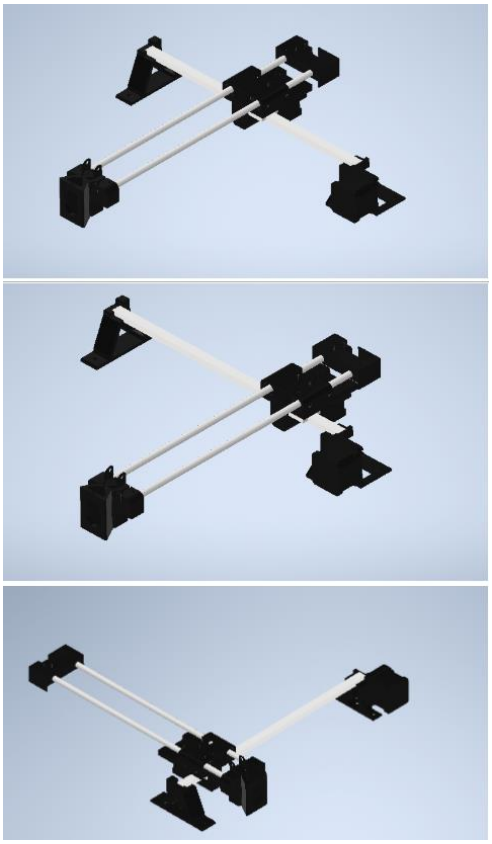


Figure 22. Milestone 4 – Pen Plotter Model Assembly

Physical Prototype for Testing:

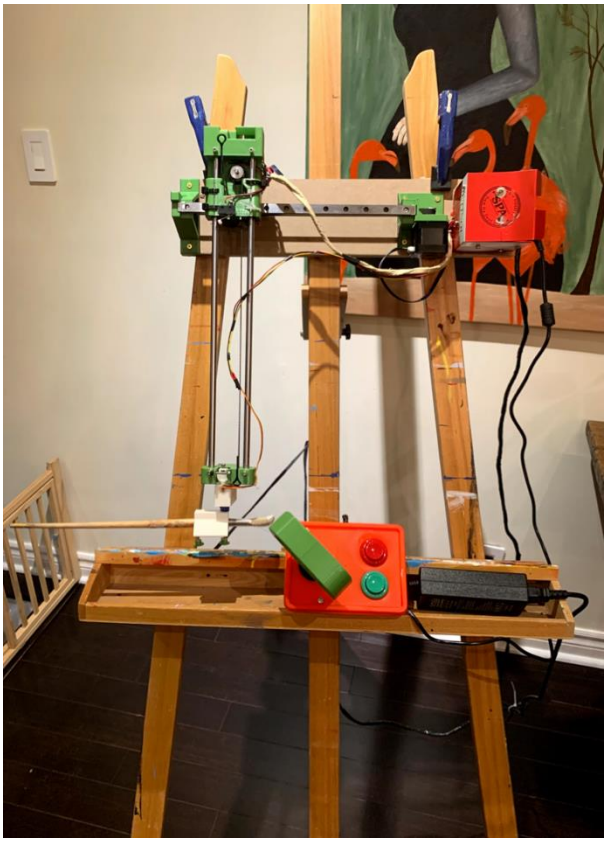


Figure 23. Paint-A-Nator 9001 (Pen Plotter clamped onto easel, Joystick device resting on easel)

Section 3

Final Drawings:

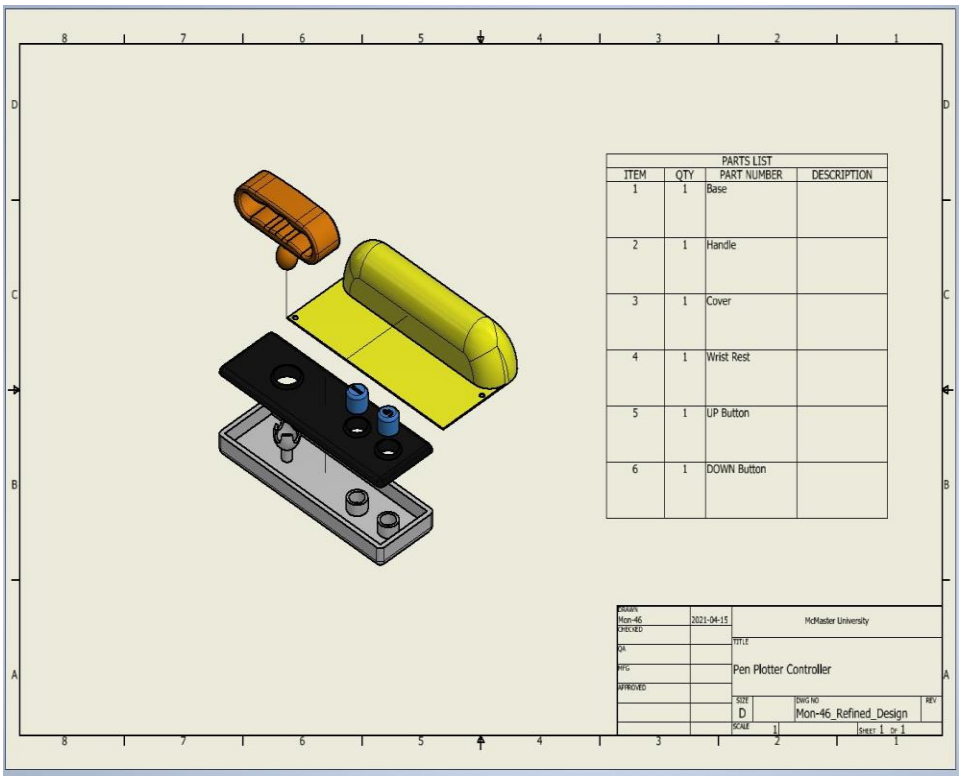


Figure 24. Exploded View of Joystick Device

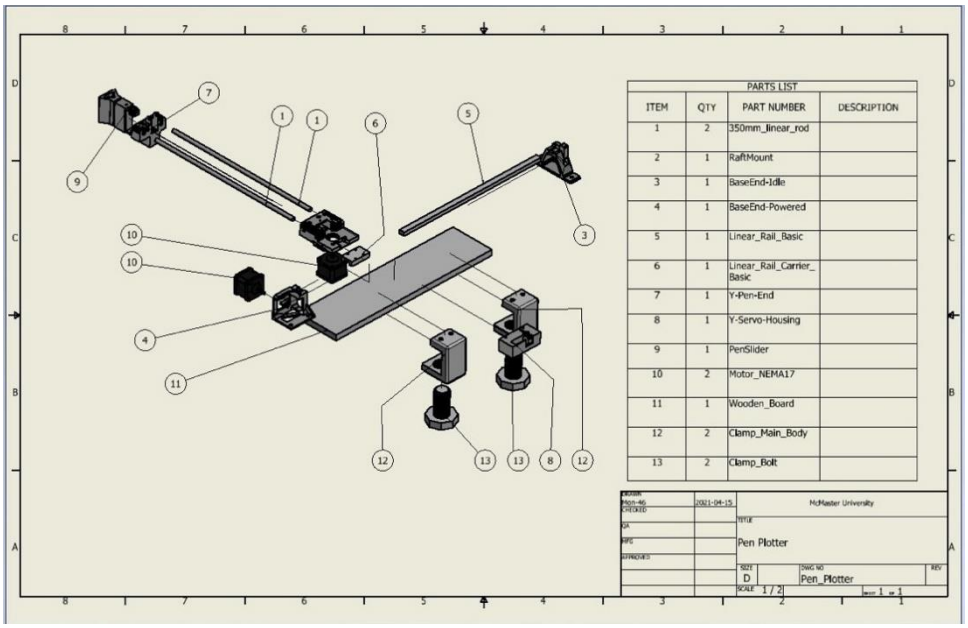


Figure 25. Exploded View of Pen Plotter

Final Prototype:

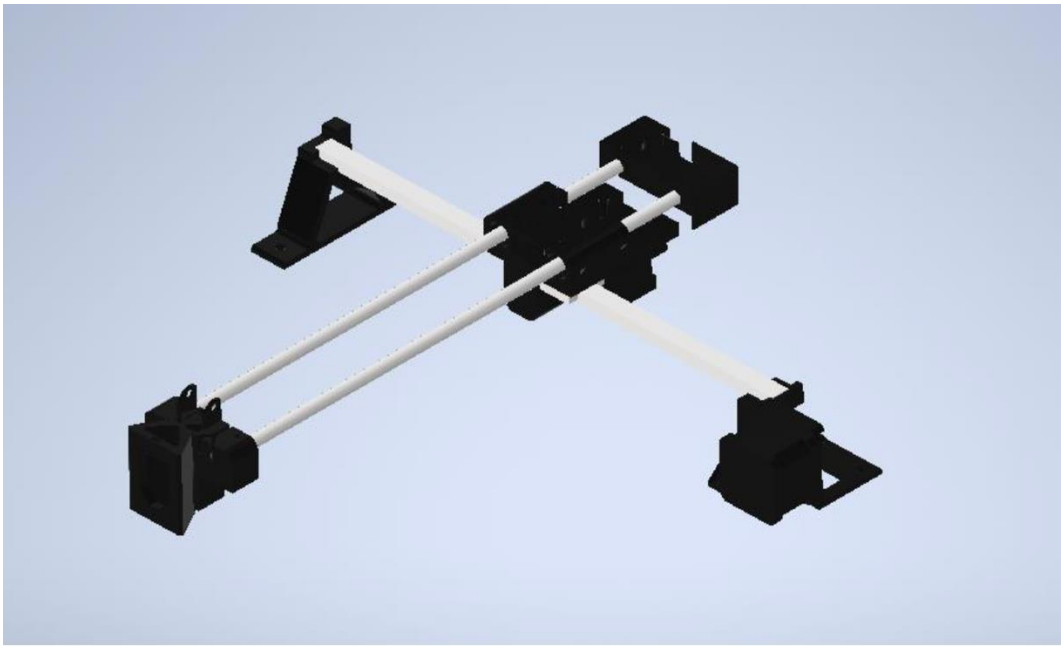


Figure 26. Final Prototype Angle View of Pen Plotter

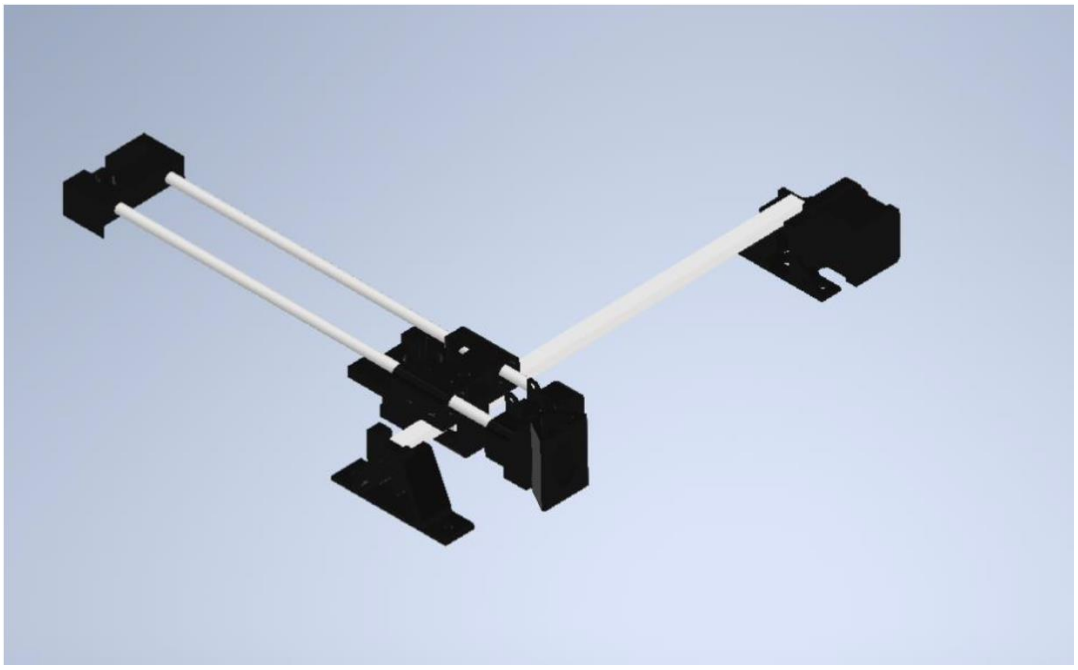


Figure 27. Final Prototype Different Angle View of Pen Plotter

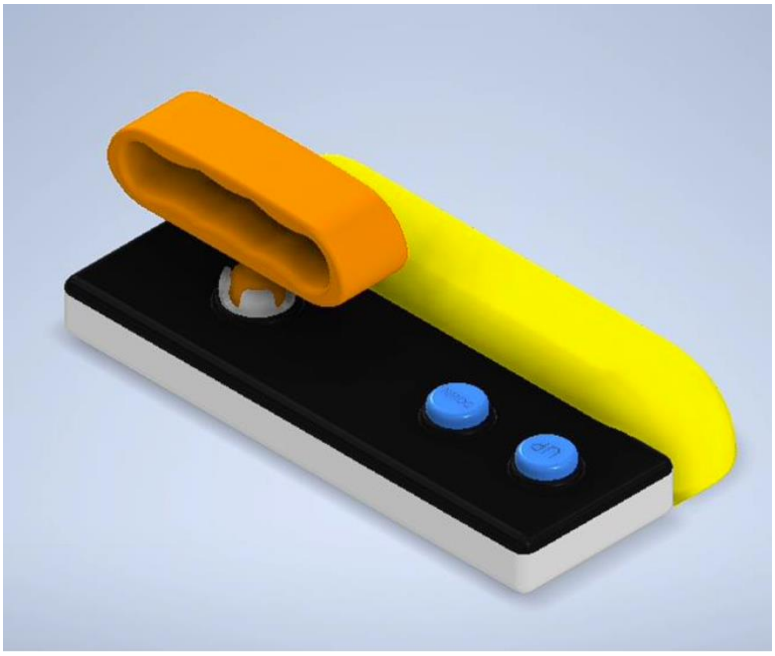


Figure 28. Final Prototype Angle View of Joystick Device

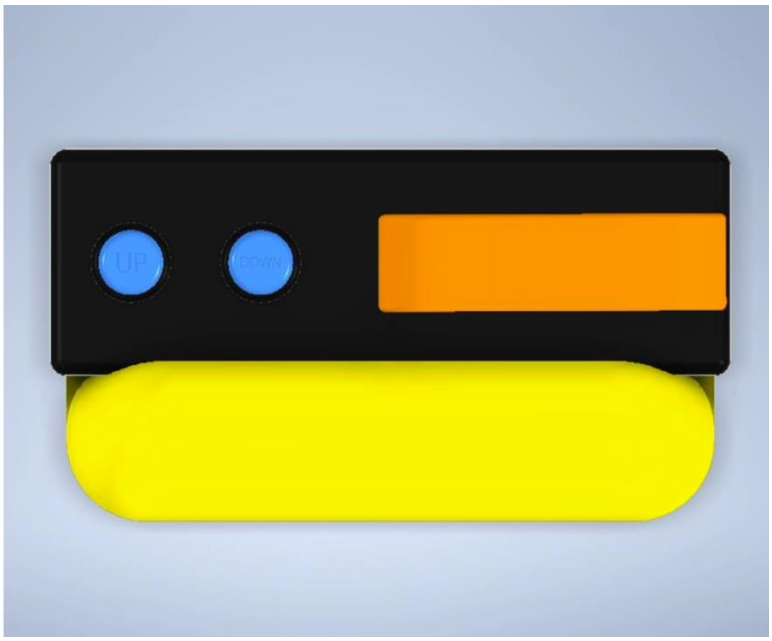


Figure 29. Final Prototype Top View of Joystick Device

Bill of Materials:

Name	Specification	Price	Link
3D Printing Filament	1.75mm 1KG	$19.95	Filaments.ca
Power Supply	12V 6A	$23.99	Amazon.ca
Linear Rod	8mm diameter, 400mm long	$20.53	Amazon.ca
Linear Rod	8mm diameter, 500mm long	$30.89	Amazon.ca

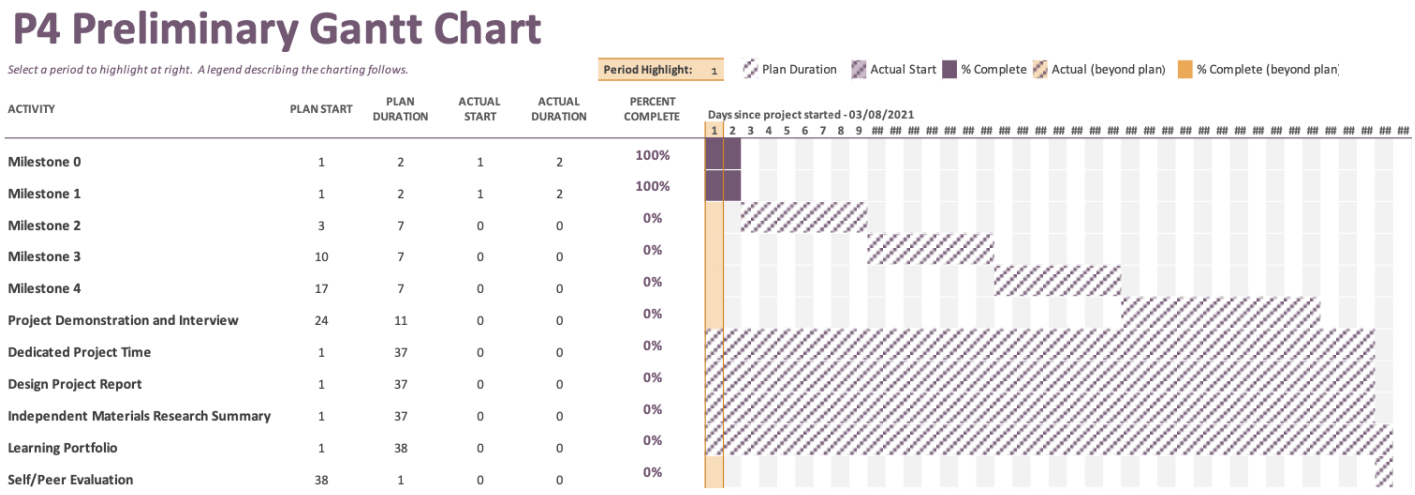
Motor Driver	2 Pack L298N	$13.99	Amazon.ca
2x SIMAX3D Stepper Motors	NEMA 17	$37.98	Amazon.ca
GT2 Smooth Timing Pulley	3mm Bore	$11.99	Amazon.ca
Linear Rail	300mm	$32.29	Amazon.ca
Microswitch	10 Pcs	$11.99	Amazon.ca
SG90 Servos	5 Pcs	$19.99	Amazon.ca
GT2 Set	Timing Belt, 4 Teeth Pulleys	$15.99	Amazon.ca
Linear Bearings	25mm Long	$20.29	Amazon.ca
Linear Bearings	45mm Long	$16.99	Amazon.ca
Lock Nut	Assorted (M3-M12)	$15.99	Amazon.ca
Fastener Kit	Assorted (M2-M5)	$34.89	Amazon.ca
Scrap MDF	5/8” Thick	$5.00	On Hand
Total Price		**$332.65**	

Table 3. Bill of Materials

Appendix B: Section 4-5

Section 4

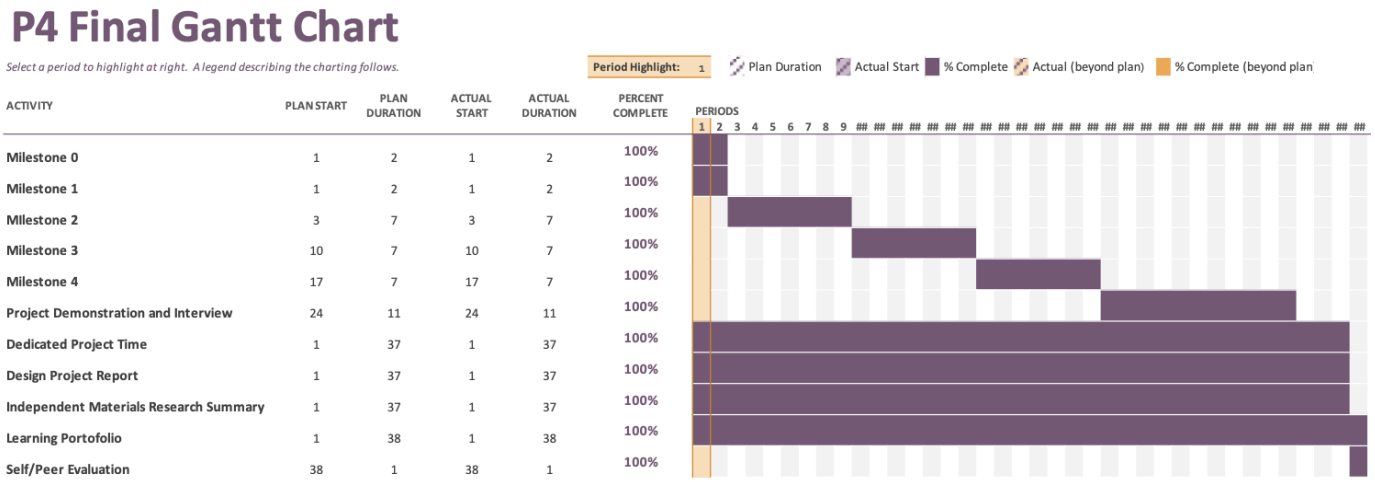
Preliminary Gantt Chart:



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Milestone 0	1	2	1	2	100%
Milestone 1	1	2	1	2	100%
Milestone 2	3	7	0	0	0%
Milestone 3	10	7	0	0	0%
Milestone 4	17	7	0	0	0%
Project Demonstration and Interview	24	11	0	0	0%
Dedicated Project Time	1	37	0	0	0%
Design Project Report	1	37	0	0	0%
Independent Materials Research Summary	1	37	0	0	0%
Learning Portfolio	1	38	0	0	0%
Self/Peer Evaluation	38	1	0	0	0%

Figure 30. Project 4 Preliminary Gantt Chart

Final Gantt Chart:



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Milestone 0	1	2	1	2	100%
Milestone 1	1	2	1	2	100%
Milestone 2	3	7	3	7	100%
Milestone 3	10	7	10	7	100%
Milestone 4	17	7	17	7	100%
Project Demonstration and Interview	24	11	24	11	100%
Dedicated Project Time	1	37	1	37	100%
Design Project Report	1	37	1	37	100%
Independent Materials Research Summary	1	37	1	37	100%
Learning Portofolio	1	38	1	38	100%
Self/Peer Evaluation	38	1	38	1	100%

Figure 31. Project 4 Final Gantt Chart

Logbook of Additional Meetings and Discussions:

Friday March 5th, 2021

- Attendance
  - Ariel Wolle
  - W. Tisuka Perera
  - Milica Nenadovic
- Intros
- Organize Roles
- Complete Milestone 0
- Start Milestone 1

Monday March 8th, 2021

- Attendance
  - Ariel Wolle
  - W. Tisuka Perera
  - Milica Nenadovic
  - Yara Sharafeldin
- Intros
- Review and Refinement of Milestones 0 and 1

Friday March 12th, 2021

- Attendance
  - Ariel Wolle
  - W. Tisuka Perera
  - Milica Nenadovic
  - Yara Sharafeldin (½ hour)
- Type Out Client Notes
- Finish Researching

Monday March 15th, 2021

- Attendance
  - Ariel Wolle
  - W. Tisuka Perera

- Milica Nenadovic

❖ Technical Difficulties

❖ Finish Concept Sketches

❖ Finish Milestone 2

Friday March 19th, 2021

❖ Attendance
- Ariel Wolle
- W. Tisuka Perera
- Milica Nenadovic
- Yara Sharafeldin

❖ Participated in Design Review #1

❖ Started Milestone 3

❖ Reflected on Design Review Notes

Monday March 22nd, 2021

❖ Attendance
- Ariel Wolle
- W. Tisuka Perera
- Milica Nenadovic
- Yara Sharafeldin

❖ Finished up Milestone 3

Friday March 26th, 2021

❖ Attendance
- Ariel Wolle
- W. Tisuka Perera
- Milica Nenadovic
- Yara Sharafeldin

❖ Participated in Design Review #2

❖ Read through Milestone 4

❖ Reflected on Design Review Notes

Monday March 29th, 2021

- Attendance
  - Ariel Wolle
  - W. Tisuka Perera
  - Milica Nenadovic
  - Yara Sharafeldin
- Split up work
- Organized meeting to finish Milestone 4

Monday April 5th, 2021

- Attendance
  - Ariel Wolle
  - W. Tisuka Perera
  - Milica Nenadovic
- Finish up CAD
- Start Design Report Write-up

Friday April 9th, 2021

- Attendance
  - Ariel Wolle
  - W. Tisuka Perera
  - Milica Nenadovic
- Prepare and Planned Video
- Organize Design Report

Monday April 12th, 2021

- Attendance
  - Ariel Wolle
  - W. Tisuka Perera
  - Milica Nenadovic
- Presentation Organization
- Presentation

Section 5

Source Material Database:

1. H. Brorson, A. Warren, L. J. Borud, S. A. Slavin, “Lymphedema: A Comprehensive Review,” Annals of plastic surgery, Oct-2007. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/17901744/. [Accessed: 12-Apr-2021].

2. D. J. Clauw, “Fibromyalgia: an overview,” The American journal of medicine, 2009. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/19962494/. [Accessed: 12-Apr-2021].

3. E.B. Gouveia, D. Elmann, M.S. Morales, “Ankylosing spondylitis and uveitis: overview,” Rev Bras Reumatol, Oct-2012. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/23090374/. [Accessed: 12-Apr-2021].

4. D. I. Y. Machines, “Easy 3D Printable CNC Drawing Machine.” [Online]. Available: https://www.thingiverse.com/thing:4537916. [Accessed: 14-Apr-2021].

5. “AxiDraw MiniKit 2 – Compact Pen Plotter DIY-Kit,” Elektor. [Online]. Available: https://www.elektor.com/axidraw-minikit-2-compact-pen-plotter-diy-kit. [Accessed: 14-Apr-2021].