Phase 2 Report: Prosthetic Limb Control System Design

Team #26

A Report
Presented to
The Department of Electrical and Computer Engineering
Concordia University

In Partial Fulfillment
of the Requirements
of ELEC/COEN 490

By

Vincent Beaulieu	40062386
Samantha Famira	40094949
Suyash Sinha	40096587
Mark Zalass	40097293
Hamza Shah	40092722
Karl Noory	40059592

Project Supervisor
Dr. Rodolfo Coutinho

Concordia University
November 2021

ABSTRACT

For individuals with transradial amputations, myoelectric prosthetic devices are an available solution for artificial limb replacement. A myoelectric prosthetic device uses electromyographic (EMG) signals resulting from contraction of the muscles in the residual limb to control movement of the prosthesis. One of the primary myoelectric control techniques used with these devices is pattern recognition. The goal of our project is to design and develop a myoelectric control system which uses pattern recognition to control the hand of a pre-existing electric transradial prosthetic device. Additionally, our system will provide vibratory feedback to the user to indicate when the prosthetic hand is in contact with a surface. This report will provide a review of the specifications and an overview of our design thus far. An analysis of the alternatives which lead to our selection of the control algorithm and the processing hardware will be presented. The development of the design will then be detailed, including the hardware components and the software systems. Next, the updated schedule and list of tasks are given. Additionally, an investigation into the ELSEE aspects of our project will be given. Finally, the contributions of each team member up to this point will be included. The result of this report is a documented design for our system and a clarified plan and schedule for the upcoming phases.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. REVIEW OF DESIGN SPECIFICATIONS

1.1 Specifications

Table 1: Specifications Table

Description/Parameter	Test Condition	Value			Unit
		Min	Typical	Max	
Response Time	STP*			250	ms
Servo Motor Voltage (HK15298)	STP*	4.8	6	7.4	V
Servo Motor Current (HK15298)	STP*	5	120	1800	mA
Force Sensor (FSR07BE)	STP*			4	kg
Force Sensor Actuation Force (FSR07BE)	STP*		0.67		MΩ/g
Force Sensor Active Area Diameter (FSR07BE)	STP*			14.7	mm
EMG Electrode Sampling Rate	STP*	2.5		2.5	kHz
Haptic Feedback Vibration DC Motor Rated Voltage (JQ24-35F580C)	STP*	0		5	V
Haptic Feedback Vibration DC Motor RPM (JQ24-35F580C)	STP*	0		2550	rpm
Haptic Feedback Vibration DC Motor Rated Load Current (JQ24-35F580C)	STP*			150	mA
Status LED Forward Voltage (C503B-GCN-CY0C0792)	STP* Forward Current If = 20mA		3.2	4.0	V

** STP: Standard Pressure and Temperature*

1.2 Review of Design Specifications

Most of the specifications listed were set by the manufacturer of the parts and were obtained by the referenced datasheets. Some specifications were set by the team, they are described below.

1.2.1 Reaction Time

As the typical human reaction time is 250ms [1], a response time of 250ms between a muscle movement occurring and an arm movement starting was chosen.

1.2.2 EMG Electrode Sampling Rate

For the EMG electrode sampling rate, the required frequency was found to be 500 Hz, as this is the max frequency of an EMG signal [2]. Theoretically, the Nyquist frequency would be taken as the chosen frequency (2 x 500Hz = 1000 Hz) [3] but to account for real-world discrepancies, a frequency of 5 times the required frequency was chosen, giving a chosen frequency of 2.5 kHz (5 x 500Hz = 2500 Hz).

2. DESIGN REVIEW

In this section, we will give a brief overview of our design thus far. In the subsequent sections, we will give a detailed explanation for each design component presented.

2.1 Hardware System

2.1.1 Overview of the Hardware System

In Figure 1, we give a high-level view of the full hardware system, which includes the movement control system and the haptic feedback system.

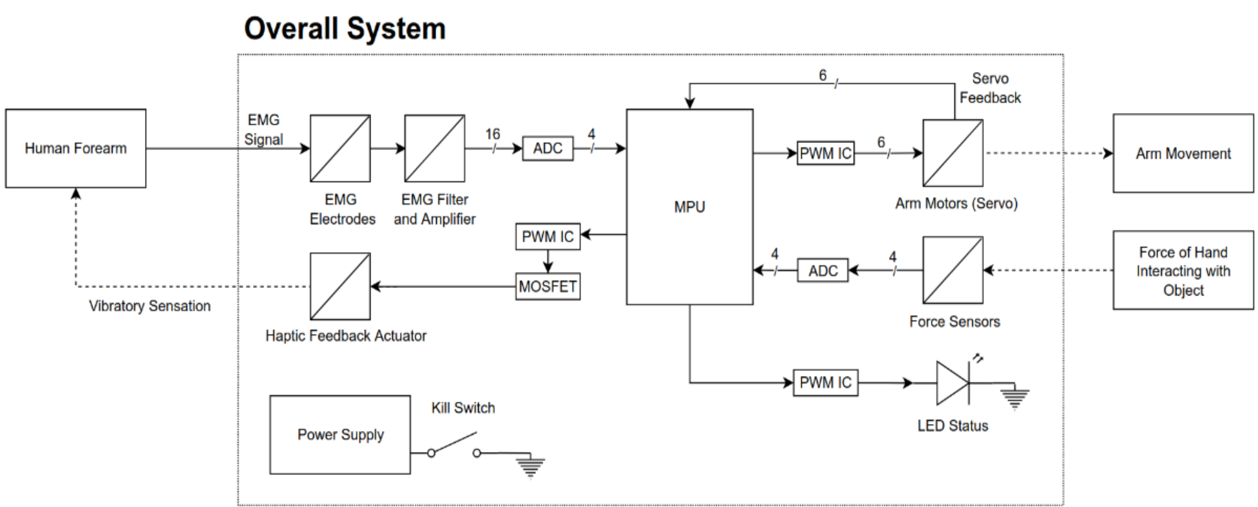

Figure 1: Overview of the Entire System

2.1.3 Amplifying and Filtering Electric Circuit

The electric circuit for the amplifying and filtering of the EMG signals obtained from the EMG electrodes is demonstrated in Figure 2.

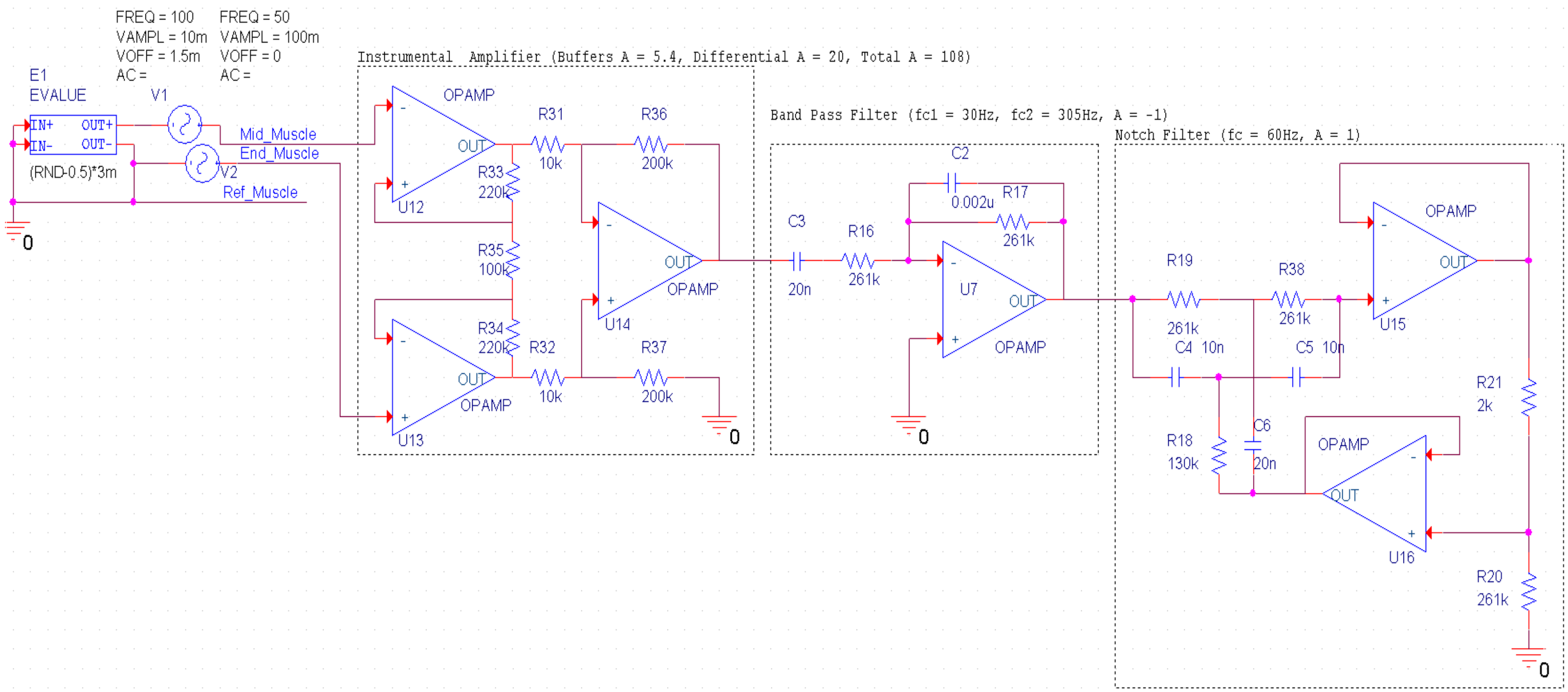

Figure 2: Amplifying and Filtering Circuit

2.1.4 Overall Simplified Electric Design

The circuit design that we developed is composed of various stages. At the input of the circuit, we have a noise generator that we used for simulation purposes only, the actual amplification units start at the notation “Mid Muscle, End Muscle, Ref Muscle” which correspond to the surface electrode inputs to read the muscle signals. The pair of electrodes are summed together and amplified to a maximum value of 5V proportional to the EMG reading, then filtered through a band-pass filter of ~30 to ~300 Hz and a Notch filter at 60Hz, before being fetch to the second stage of the circuit, being the bipolar ADCs, and finally, the controller. [4] [5]

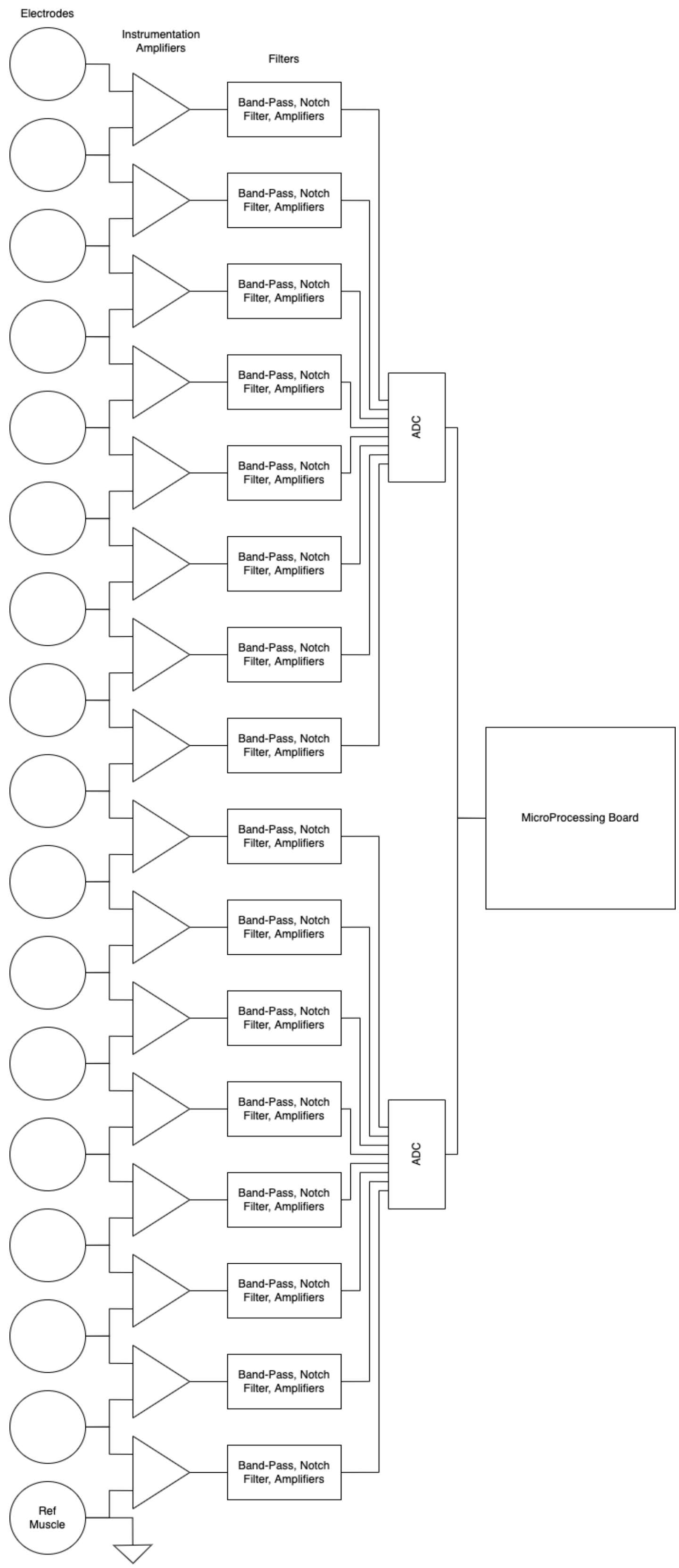

Figure 3: Overall Simplified Electric Design

2.2 Software System

2.2.1 Overview of the Software System

The flow diagram for the overall software system is displayed in Figure 4. This flow diagram incorporates the filtering of the data, mapping of the data to a movement, and the haptic vibration feedback.

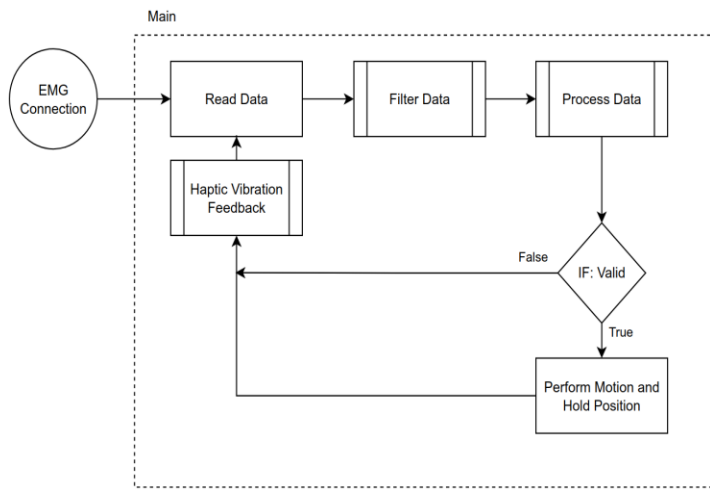

Figure 4: Flow Diagram for Overall Software System

2.2.2 Filter Data Algorithm

The flow diagram displayed in Figure 5 describes the algorithm for the Filter Data block in the overall system view.

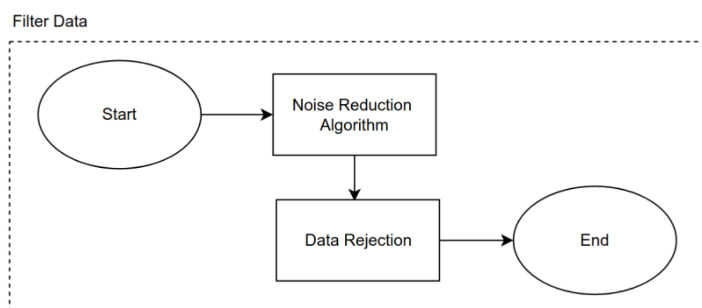

Figure 5: Data Filtering Algorithm

2.2.3 Haptic Feedback Algorithm

Displayed in Figure 6 is the flow diagram which describes the algorithm for the haptic vibration feedback block in the overall system.

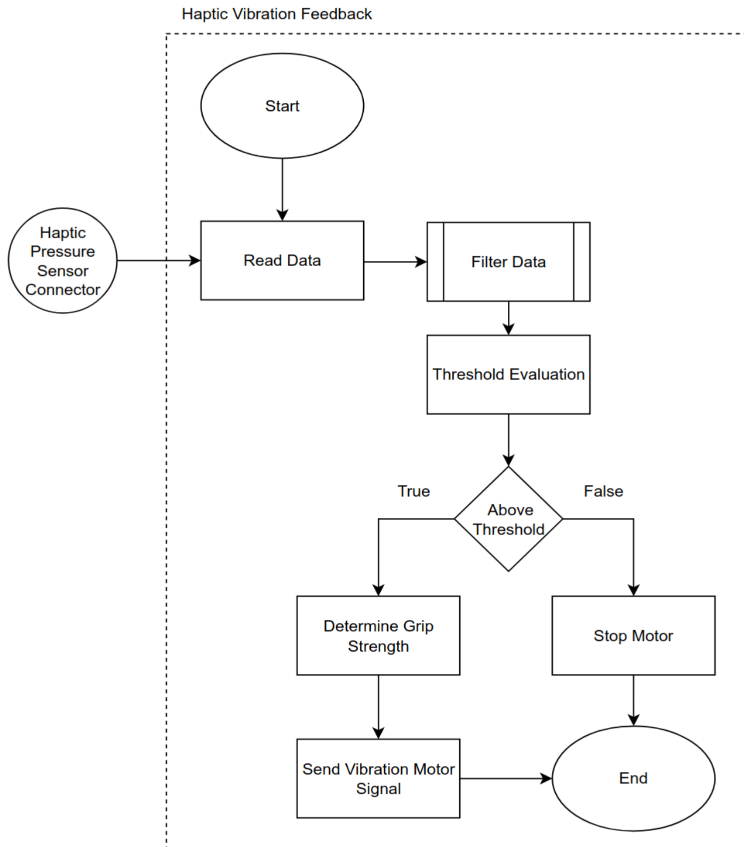

Figure 6: Flow Diagram for the Haptic Feedback Algorithm

2.2.4 Mapping Data to Movement

The process data block in the overall system view is shown in Figure 7. This describes the algorithm which will map the EMG data to a movement.

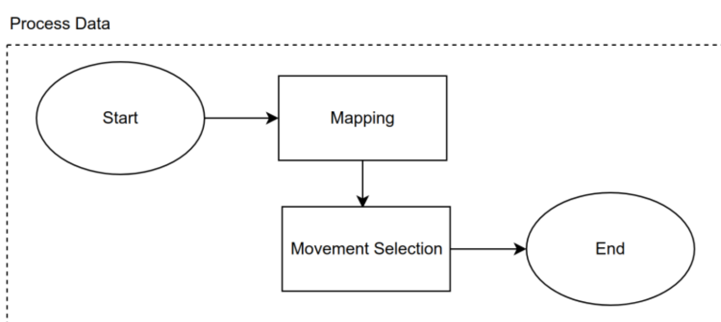

Figure 7: Flow Diagram for the Process Data Algorithm

3. ALTERNATIVES

This section will analyze the alternatives for our design, specifically the core components of the design: the control algorithm and the hardware processing components. Firstly, the alternatives for the myoelectric control algorithm will be investigated and evaluated. Based on the algorithm chosen, the alternatives for the processing hardware are to be analyzed.

3.1 Algorithm Alternatives

Myoelectric prostheses use EMG signals as input for control. The main control algorithms implemented in these devices are amplitude-based algorithms and pattern recognition. The amplitude-based algorithms, such as direct control and proportional control, typically use signals from two EMG channels on opposing muscle groups to trigger movements. The contraction of a muscle is mapped directly to a movement, such as hand-open and hand-closed, and is triggered once the amplitude of the EMG signal reaches a certain threshold. Co-contraction may be used to cycle through various grip patterns. On the other hand, pattern recognition analyzes patterns within the EMG signals using machine learning and maps these patterns to movements using classifiers which have been trained with EMG data matched to specific movements. [3] [6]

To compare these two types of algorithms, we selected key criteria to analyze. This criterion includes the implementation complexity/time, the number of achievable movements, the ease of use (how intuitive the control is to use), the cost, and the processing delay. The information used for the analysis is mainly taken from the paper “Prosthetic Myoelectric Control Strategies: A Clinical Perspective” [6]. Table 2 describes the alternatives in terms of these parameters. Table 3 gives each algorithm a score out of 10, based on these parameters.

Based on the analysis shown in Tables 2 and 3, the pattern recognition control is the selected control algorithm. Compared to the amplitude-based control, the implementation of pattern recognition will require more time and introduce greater complexity. Additionally, the cost will be higher. But given these downsides, the advantages of pattern recognition control are that we will be able to achieve a greater number of movements, and it is a less cognitive demanding control mechanism for the user, which we value highly.

Table 2: Comparison of the Control Algorithm Alternatives

#	Criteria	Weight	Alternatives	
			Amplitude-Based Control	**Pattern Recognition Control**
1.	Implementation complexity/time	15	Simpler implementation based on a threshold-amplitude comparison. Less time consuming.	More complex implementation using machine learning algorithms. More time consuming due to the need for training.
2.	Number of achievable movements	20	Limited number of movements	Higher number of achievable movements.
3.	Ease of use	30	Less intuitive control. User must explicitly contract specific muscles in a way that is unrelated to the natural movement. Requires more cognitive effort.	More intuitive control. User can contract muscles in a natural way to achieve movements. Requires less cognitive effort
4.	Cost	20	Requires less processing power and less sensors, so less costly.	Requires more processing power and a slightly higher number of sensors, so more costly.
5.	Processing delay	15	Fast, as less processing needed, and amplitudes can be directly mapped to motion.	Slightly slower, as more computation required, and processing window length must be sufficient to extract features from the EMG signals.

Table 3: Scoring of the Algorithm Alternatives

#	Criteria	Weight	Alternatives	
			Amplitude-Based Control	**Pattern Recognition Control**
1.	Implementation complexity/time	15	9	6
2.	Number of achievable movements	20	6	8
3.	Ease of use	30	4	8.5
4.	Cost	20	8	6
5.	Processing delay	15	8	7
		100	6.55	**7.3**

3.2 Processing Hardware Alternatives

The analysis of the control algorithm led to the selection of pattern recognition. Based on this selection, the alternatives for the processing hardware can be evaluated. Due to the control algorithm selected, we must decide between using a microcontroller or a microprocessor. For these two alternatives we could use an Arduino Mega 2560 Rev3 or a Raspberry Pi 4. Since the pattern recognition algorithm uses machine learning, our choice of processing unit will require sufficient processing power and RAM, but also the use of library for which, python is more appropriate (sklearn/tensorflow). The choice between an Arduino and a Raspberry Pi is evaluated on the following criteria: processing power, RAM, programming languages for development, price, and GPIOs. The different criteria for the alternatives are shown in Table 4 with their scores given in Table 5.

Based on the scores given in Table 5, the chosen hardware for the processing is the Raspberry Pi 4. Though the cost will be higher with the Raspberry Pi in comparison to the Arduino, and there are a smaller number of GPIO, the greater processing power and RAM available with the Raspberry Pi are an advantage. Additionally, since the Raspberry Pi can be programmed using Python, this will greatly ease the implementation of the pattern recognition algorithm, which is a significant advantage to our design.

Table 4: Comparison of the Processing Hardware Alternatives

#	Criteria	Weight	Alternatives	
			Arduino Mega 2560 Rev3	**Raspberry Pi 4**
1.	Processing Power (Clock Speed)	35	16 MHz	1.5 GHz
2.	RAM	30	256 KB	2 GB
3.	Programming Language Supported	20	C, C++	C, C++, Python
4.	Cost	5	~ 44.00 $	~ 60.00 $
5.	GPIO	10	54 (out of which 15 provide PWM)	26 (out of which 2 provide PWM)

Table 5: Scoring of the Processing Hardware Alternatives

#	Criteria	Weight	Alternative Scores	
			Arduino Mega 2560 Rev3	**Raspberry Pi 4**
1.	Processing Power (Clock Speed)	35	5	9
2.	RAM	30	3	7
3.	Programming Language Supported	20	6	8
4.	Cost	5	9	2
5.	GPIO	10	8	5
			6.5	**7.45**

4. SELECTED SOLUTION

Based on the analysis of the alternatives, pattern recognition is the selected solution for the control algorithm for the pre-existing 3D-printed prosthetic hand. This control algorithm will generate a more intuitive and less cognitively demanding control method for the user. Based on the control algorithm selected, the evaluation for the processing hardware component led to the choice of a microprocessor, the Raspberry Pi 4. This choice will give us the power necessary to train the machine learning algorithm on board. It also permits us to use python, which has a vast number of libraries dedicated to machine learning.

Overall, the system will be composed of a microprocessor, 16 EMG electrodes, an electrical filtering and amplifying circuit 6 servo motors, a vibratory feedback motor, and 4 force sensors. All the components for the system and their costs are listed in Appendix A. The EMG filtering and amplifying circuit is designed in OrCAD. There will be some hardware filtering done by the circuit. There will also be some software filtering done on the input to remove outliers in the signal. The pattern recognition will use machine learning therefore the model will have to be trained. The trained pattern recognition algorithm will map the EMG sensor input to corresponding movements for the servo motors to produce.

The system will include haptic feedback, where a motor will create a proportional vibration to the input to the force sensor. There will also be an LED for visual feedback. The two forms of feedback are for redundancy and/or to provide feedback to users that has reduced sensation. The LED will indicate that there are in fact signals being read in the case that the haptic feedback is non-functional. The system design will be non-mobile and limited to be plugged into a power supply.

5. DESIGN DEVELOPMENT

5.1 Hardware Design Development

5.1.1 Wearable Device

Based on the requirements to read the residual EMG signals in the forearm for muscle movement, to provide the user with haptic grip force feedback, and that the control system should be wearable on the forearm, it was decided that an armband would be designed which would contain both the sensors to detect the muscle movement and the haptic feedback mechanism. Figure 8 displays the general idea of the wearable system.

To enable the haptic force feedback, it was decided to implement the haptic feedback using a DC vibration motor embedded in the arm band. The DC vibration motor chosen is the Jinlong JQ24-35F580C. The motor was chosen as it has a light weight of 30g and a cost of $5. The motor would activate when pressure is detected on the fingers of the arm to provide the user with a vibration sensation when the prosthetic arm fingers grasp an object.

To capture the muscle signal of an amputee, two different sensors were considered, EMG sensors and ultrasonic sensors. EMG sensors were chosen as they are easier to acquire and more cost-effective than ultrasonic sensors, in addition EMG sensors are the type of sensor commonly most found in commercial prosthetic arm implementations. It was decided to use 8 channels of EMG sensors which results in 16 EMG sensor probes. Sixteen sensors were chosen as research [3] indicated that the most efficient sensor configuration was between 8 and 24 sensors. It was believed that 8 sensors would not be enough to enable proper machine learning and that 24 sensors would over-complicate the circuit design, so 16 sensors were chosen as a compromise.

To process the EMG signals, a circuit design was produced. The EMG signals will first pass through an instrumental amplifier [4]. The Texas Instruments INA2332AIPWR instrumental amplifier was chosen as it produces low noise into the signal. The amplifier will first amplify the differences of the two electrodes of each EMG channel and then it will amplify the signals to a total gain of 100.

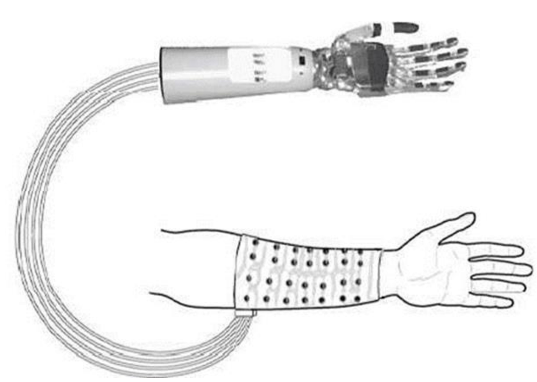

Figure 8: Wearable Sleeve with EMG electrodes [7]

The signals will then pass through a Band Pass filter which will allow only signals between 30 Hz and 305 Hz, which is the frequency range of muscle EMG signals. The signals then pass through a notch filter, which will filter out the 60 Hz noise generated by the 60 Hz AC power.

5.1.2 Prosthetic Arm

The requirements for the prosthetic arm were that the arm must be able to perform finger-level movements, be able to perform 6 identified hand gestures and read the force of an object being grasped to enable haptic force feedback to the user. The prosthetic arm chosen is a pre-existing prosthetic arm, displayed in Figure 9, that was loaned from the university. The arm was 3D printed and contains 7 existing servo motors which gives it the ability to move individual fingers and the wrist. As the arm is open source, all the files needed to 3D print replacement parts are available.

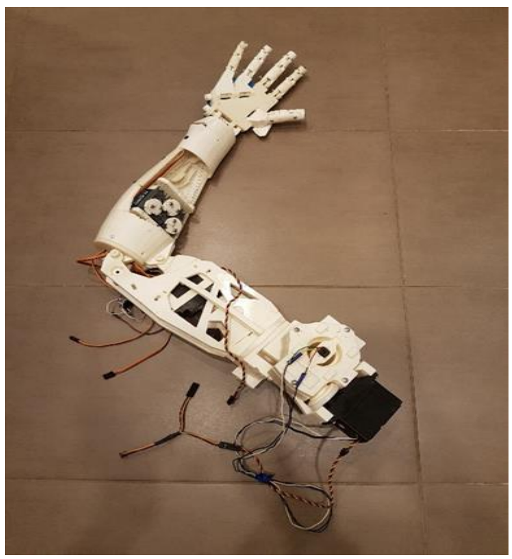

Figure 9: The Prosthetic Arm to be Controlled

The safety of the user and others is an important requirement for the project. To address safety concerns, the arm will contain an LED indicator to indicate to the user that the arm is functional and will indicate if any errors occur. A kill switch for control of the arm will also be present on the power supply so that the user can deactivate it if any malfunctions or undesired movements occur. The arm will be surrounded by a cage during the Capstone demo to protect the user and others while the arm is operational.

To enable the haptic feedback, force sensors will be embedded into the fingertips. The FSR07BE force sensors will be used, as their active area of 1.5 cm corresponds with the size of the fingertips of the chosen prosthetic arm. 5 force sensors will be used, one for each fingertip.

5.1.3 Processing Unit

The requirements for the processing unit were that it would be able to handle running the machine learning algorithm in python and require a significant amount of RAM and processing power. The processing unit must also be able to communicate with the servos in PWM. The Raspberry Pi 4 was chosen as it has 2 GB of RAM and a 1.5 GHz CPU [8], enough processing power to handle machine learning.

As the Raspberry Pi 4 only has 2 PWM slots, an external board is needed to allow the Raspberry Pi 4 to communicate with all 7 servos and the haptic feedback actuator. The Adafruit 16-channel PWM/Servo Shield was chosen to extend the PWM slots to accommodate all the PWM components.

The Raspberry Pi 4 does not have a built-in ADC to communicate with the EMG sensors. To address this deficiency, an AD/DA expansion board will be added to the Raspberry Pi 4. The Texas Instruments ADS1255/ADS1256 24-bit Analog-to-Digital Converter was chosen due to its low noise interference and ability to handle 8 analog inputs for the 8 EMG channels [9].

5.2 Software Design Development

5.2.1 EMG Data Processing and Arm Movement Algorithm

Referencing the state diagram referring to the EMG data processing and arm movement loop, the EMG data is first read into the processing unit. The data then enters the Filter Data block where the data is filtered in software, where any noise is removed using a noise reduction algorithm. Afterwards, the EMG data is processed in the Process Data block.

Originally, it was decided to use direct control to process the EMG sensor data but after more research, it was decided to use the machine learning pattern recognition approach. Pattern recognition allows for more intuitive control and greater range of motions compared to direct control. This decision is explained in detail in section 3.1. The process data block will first map the signal from each EMG sensor to each muscle using a machine learning mapping algorithm. It is intended to use the K nearest neighbor's classifier machine learning algorithm. If the results produced by the algorithm are not desirable, the Linear discriminant analysis algorithm will be used. Once the data is processed, if the signal represents a valid movement, the arm will perform its motion. If no valid movement is detected, the arm will not perform a motion.

5.2.2 Haptic Vibration Feedback Algorithm

Referencing the state diagram referring to the haptic vibration feedback algorithm, the haptic pressure sensor data is first read. The data is then filtered to remove any noise. If the pressure sensed by the pressure sensors is above the threshold to trigger the vibration feedback, the strength of the vibration feedback will first be determined. The vibration feedback signal will then be sent to the vibration motor. If the pressure sensed by the pressure sensors is below the threshold to trigger the vibration feedback, the signal to operate the vibration feedback will be stopped.

6. REVISED TASK ALLOCATION AND SCHEDULE

Since phase 1, more research was done, and decisions were made for the design. This led to clarification on the steps necessary to be taken in the development of the project. Consequently, some tasks were added, and some were removed. Additionally, as per suggestions from phase 1, a team member was designated as a lead for each task, with an additional team member or team members, as support. Below is the newly modified list of tasks and the modified schedule can be found in Appendix B.

1. Wearable device (Lead: Suyash, Support: Karl)
    - Sleeve design with PCB and 16 electrodes inside
    - Wiring of the sleeve to the controller

2. Hardware system (Lead: Karl, Support: Hamza)
    - Design PCB (KiCAD)
    - Order PCB (JLCPCB, OSHPark)
    - Order components (Digikey)
    - Solder components (in the lab)
    - Test PCB (in the lab)

3. Software system
    - Implement haptic feedback algorithm
        - Lead: Samantha, Support: Hamza, Mark
    - Implement data filtering algorithm
        - Lead: Karl, Support: Suyash
    - Implement the process data algorithm (Machine learning algorithm)
        - Lead: Vincent, Support: Suyash
    - Integrate all algorithms into main algorithm
        - Lead: Hamza, Support: Mark
    - Clone project to Raspberry Pi and test using dummy data
    - Establish communication between the hardware and software
    - Test using data coming from EMG sensors

4. Testing (Lead: Mark, Vincent)
    - Determine if the system satisfies test cases established in test plan
        - Haptic feedback system
        - Motion control system
        - Integrated system

7. ELSEE ASPECTS

The first step of ELSEE is to identify the stakeholder. It is important to address the stakeholder of the product since it gives awareness of the expectations of the stakeholder related to the innovation. This will allow us to better refine the product.

7.1 Identifying Stakeholders

- **People with upper limb forearm amputation (our customers)**:
  These individuals will benefit from an improved control system for hand prosthesis.
- **Companies that develop prosthetic devices**:
  Companies that develop prosthetic devices from A-Z could integrate our control system into their devices, improving their product and sales, etc.
- **Investors/shareholders in the companies/product**:
  Shareholders would benefit financially from improved products in the companies they invest in. Investors in the product would benefit from a successful design.
- **Suppliers (such as Digikey, Printfarm(ShapeWays) and filaments companies):**
  Companies that provide the material to develop the control system would benefit from increased sales.
- **Healthcare professionals (Doctors, specialists):**
  Doctors and specialists will be involved in offering patients the prosthetic arm as a possible solution.

Based on these stakeholders, we rank them in importance. The most important stakeholders for our product are the users: people with upper limb forearm amputations.

Ranking:

1. People with upper limb forearm amputation
2. Companies that develop prosthetic devices
3. Healthcare professionals
4. Digikey, Printfarm, and filaments companies
5. Investors/Shareholders

7.2 Identifying Desired Features of the Stakeholders

The second step of ELSEE is to identify desired features of the stakeholders. This will provide insight towards current and future societal impact of the innovation.

For people with upper limb amputations which use prosthetic devices:

A literature review on the needs of upper limb prosthesis users [10], identified these specific needs:

- Sensory feedback and adaptability of grip strength
- Improvement of movement and grip
- Ability to perform basic everyday task (cooking, eating, dressing, personal hygiene)
- More affordable pricing

For companies that develop prosthetic devices:

- Ease of implementation
- Improved product (leads to satisfied consumers, more sales)

For suppliers and filament companies:

- Successful product (leads to more production, more sales for the suppliers).

For Investors/Shareholders:

- Successful product (company growth, return on investment)

7.3 Learning from experts

The third step of ELSEE is to learn from the experts. This provides a lens for societal perception and expectation with regards to the innovation.

"In a review of the literature, Gallagher and MacLachlan (2000) found that rates of clinical depression following amputation ranged from 21 per cent to 35 per cent" [11]. This statistic is relevant since the amputee feels this way with the options of prosthetics. To reduce psychological impact, the study "The Social Meanings of Prosthesis Use" [11] shows a prosthetic that can conceal their disability allows the users to decide whom they can disclose their disability to. This allows the user to control their perception with regards to their disabilities. To achieve this the prosthesis needs to be discreet and concealable. This study also demonstrates that the satisfaction level of the prosthesis has a positive correlation with increased social integration and an absence of emotional problems. In short, this study "suggests that it is, in part, ease of prosthesis use, and its ability to conceal limb loss/absence and ward of social stigmatization that enables social integration and the reduction of emotional problems surrounding such disability" [11]. The control system we are designing is trying to decrease the aversion to prosthetic arms. Since, we are designing a pattern recognition algorithm that should be natural to use. The EMG is a non-invasive technology that is superficially attached to the skin. It will also be able to provide proportional control to increase the usability of the product.

8. CONTRIBUTIONS

8.1 Vincent Beaulieu

I worked with Karl on developing the Data Flow diagram and the implementation of the electric circuit schematic. However, I drove the development of the Data Flow Diagram, while he was leading in the development of the circuit schematic. Having initially little experience with OrCAD, Karl helped me understand and perform simulation using the software and recall various elements of it. Following this, my contribution for the design of the hardware was in the evaluation and development of the various components of the electrical circuit, performing simulation, and doing research, to implement the most appropriate design for our system. I've also presented various stages of our circuit and data flow diagram to the Engineering in Residence and performed optimization accordingly with the rest of the team. My role was also mixed between hardware and software, where I performed a lot of research regarding the EMG hardware with Karl and Samantha, shared findings and helped the team in decision making. I also contributed to the research with Samathan and Suyash for the algorithm approaches. As being one of the few members with some machine learning experience, I've helped the team understand the base of machine learning, the benefits, and risk of using such an approach, and with the recommendation of the Engineering in Residence and Dr. Coutinho, we weighed the decision, and the most appropriate approaches were taken accordingly. I assisted in the development of the Gantt chart and assignments, evaluations, and distributions of tasks with the rest of the team.

8.2 Karl Noory

I worked on designing the main analog EMG filter and amplifier circuitry. After consulting with the Engineer in Residence, I performed the necessary changes to the EMG circuit with the help of Vincent. Additionally, I assisted Vincent in understanding how active op-amp filters work in analog circuits and then we worked together in computing the transfer functions, the gains and cut-off frequencies of each op-amp stage. Part of my tasks also included simulating the analog EMG circuits in OrCad PSpice Designer. This required figuring out how to generate random noise mimicking raw EMG signals. I also helped Vincent understand how to properly set-up the simulation profile and load the necessary libraries in OrCAD. To properly know how to filter and amplify the EMG signals, I had to understand what type of signal I was working with. Vincent helped me understand and interpret some of the research papers regarding the EMG signals which discussed the amplitude and frequency of the base signal. This knowledge would later allow us to properly design our filters and amplifiers.

Finally, I also helped Hamza in making the block diagram of the hardware system. I assisted him in making the necessary connections and determining the number of data buses needed per component. I also contributed to the software flow diagram with Vincent, helping him determine the algorithm approach that would ultimately be used for the prosthetic control.

8.3 Hamza Shah

I worked on the block diagram and flow of it on a high-level point of view. Any necessary changes for example, connection symbols, proper IEEE symbols for the diagram. Any changes needed when discussing our design with the Engineering in Residence were done by me. I was getting familiar with draw.io since this website is new to me. Karl helped me understand the different functionalities that can be used on draw.io such as: creating blocks, merging shapes, linking with arrows, and editing components.

I also worked on the deviation of the tasks and updating the Gantt chart accordingly from phase 1 to phase 2 report. Because I was finding it difficult to use the previous software, smartsheet, I used a more user-friendly software called Team Gantt. Samantha helped me understand what was written from the previous Gantt and helped me import the dates in a csv so when creating the new Gantt chart, it would speed up the process.

8.4 Suyash Sinha

My contribution is to research the alternative algorithm with Samantha and Vincent. Using the research, we were then able to discuss as a team and decide the solution selected. I was also responsible for researching the ELSEE aspect of the project. As for the report, my part is to write about the selected solution for the section for the ELSEE. I also assisted Mark write the design development.

I attended all our team meetings. Some meetings were just our teams, some meetings were our team with Dr. Coutinho, and some meetings were our team with Dmitry. Throughout these many meetings we were able to finalize our data flow diagrams and the system block diagram. We were also able to update the Gantt chart and our task breakdown for the next phases.

8.5 Mark Zalass

In the beginning of the project, I created the meeting plan, thought up the contingency plans and created the test cases and the general test plan for each feature and component of the prosthetic arm. I also came up with the idea and implementation of the haptic feedback feature, where the user would receive haptic feedback via a rumble motor if the user were able to successfully grasp an object using the prosthetic fingers.

I assisted Hamza in creating the block diagram and correcting it based on feedback received, including finding the appropriate picture for each component. I also assisted in the creation of the algorithm designs for the data flow diagrams.

I developed the design development portion of the report and was responsible for updating the design specifications and reviewing relevant specifications.

8.6 Samantha Famira

I participated in developing the overall block diagram of the system with the rest of the group. Additionally, I participated in the initial development of the various flow diagrams for the different software processes of the system and attended meetings with our supervisor and Dmitry to receive feedback on our system diagrams.

I also researched and investigated the alternatives for the control algorithms we could implement for our design. I presented this research to the team, as did Vincent and Suyash, regarding the types of control and how they work. Based on this research, an analysis of the two main alternatives for the control algorithms was developed which led to our choice of using pattern recognition for the control. Karl and I also went over and wrote up the analysis for the alternatives for the processing hardware. I also did some research to determine the number of sensors that we should use for our design, which contributed to our final decision on the number of sensors. I also did some research regarding the ELSEE aspects of our project. I helped in identifying the stakeholders and found a research paper which helped identify the needs of our most important stakeholder: the users.

Along with the rest of the team, I participated in the revision of the task breakdown, identifying the necessary tasks for the next phases. Together, we came up with a more detailed plan/schedule for the upcoming phases.

REFERENCES

[1] E. Ackerman, "Upgrade to Superhuman Reflexes Without Feeling Like a Robot," 19 07 2019. [Online]. Available: https://spectrum.ieee.org/enabling-superhuman-reflexes-without-feeling-like-a-robot

[2] S. Bhaga and L. Shaw, "Frequency spectrum of EMG signal," 31 10 2012. [Online]. Available: https://www.researchgate.net/figure/Frequency-spectrum-of-EMG-signal_fig2_232905752#:~:text=The%20frequency%20of%20an%20EMG,dominant%20between%2050%2D150%20Hz

[3] C. Igual, L. J. Pardo, J. Hahne and J. Igual, "Myoelectric Control for Upper Limb Prostheses," 30 10 2019. [Online]. Available: https://www.mdpi.com/2079-9292/8/11/1244/htm

[4] M. Z. Jamal, "Signal Acquisition Using Surface EMG and Circuit Design Considerations for Robotic Prosthesis," 17 10 2012. [Online]. Available: https://www.intechopen.com/chapters/40131

[5] R. MB, H. MS and M.-Y. F., "Techniques of EMG signal analysis: detection, processing, classification and applications," 23 03 2006. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1455479/

[6] A. Roche, H. Rehbaum, D. Farina and al., "Prosthetic Myoelectric Control Strategies: A Clinical Perspective," 25 01 2014. [Online]. Available: https://doi.org/10.1007/s40137-013-0044-8

[7] NASA, "Biosleeve: Multi-electrode EMG Sleeve Human-Machine Interface," 20 11 2021. [Online]. Available: https://www-robotics.jpl.nasa.gov/tasks/taskImage.cfm?TaskID=103&tdaID=888883&Image=198

[8] A. Piltch, "hich Raspberry Pi Should I Buy?," 11 10 2021. [Online]. Available: https://www.tomshardware.com/uk/how-to/raspberry-pi-buying-guide

[9] WaveShare, "Raspberry Pi High-Precision AD/DA Expansion Board," Waveshare, 26 03 2019. [Online]. Available: https://www.waveshare.com/product/high-precision-ad-da-board.htm

[10] F. Cordella, A. Ciancio, R. Sacchetti and al., "Literature Review on Needs of Upper Limb Prosthesis Users," 12 05 2016. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4864250/

[11] C. Murray, "The social meanings of prosthesis use," 05 2005. [Online]. Available: https://pubmed.ncbi.nlm.nih.gov/15857872/

APPENDIX A: SELECTED COMPONENTS AND COSTS

Description	Quantity	Unit Price	Extended Price CAD
Instrumentation Amplifier (contains 2)	12	3.57	42.84
Resistor 10 kΩ	20	0.08	1.60
Resistor 191 kΩ	20	0.061	1.22
Capacitor 0.1 µF	50	0.0312	1.56
Electrodes (contains 6)	3	6.73	20.19
Op-Amp (contains 4)	18	1.626	29.27
Resistor 261 kΩ	100	0.0245	2.45
Capacitor 0.02 µF	50	0.1408	7.04
Capacitor 0.002 µF	20	0.082	1.64
Resistor 130 kΩ	20	0.061	1.22
Capacitor 0.01 µF	50	0.0516	2.58
Resistor 2 kΩ	20	0.08	1.60
Force Sensor	4	10.77	43.08
Vibration Motor	2	7.9	15.80
Status LED	5	0.33	1.65
PWM Pi Shield	2	23.79	47.58
Capacitor 1000 µF	2	0.57	1.14
ADC Pi Shield	2	33.6	67.2
		Total	289.66

APPENDIX B: GANTT CHART