Affordable Universal Controller for Upper Limb Prosthetics

By

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1 Introduction

1.1 Problem

2 million people in the United States have lost a limb [3], a number that is expected to double by 2050 [1]. Despite the growing population of prosthetic-users, inexpensive prosthetic options are largely unavailable in the market. As of 2009, the medical costs of US amputation totaled over $8.3 billion [3]. The average cost associated with a myoelectric prosthetic costs about $18,703 for a partial hand and can also cost up to $61,655 for a loss at the shoulder [7]. Costs especially accumulate over a lifetime as prosthetists recommend replacing prosthetics when changes in activity, structural integrity, and compatibility of parts occur [9]. In fact, the exorbitant cost has prevented 9 out of 10 people worldwide from accessing the prosthetics they need [10].

1.2 Solution

Our project will focus on building an EMI-shielded, standalone sEMG device capable of being removed and used with various designs of prosthetic devices. We plan on designing an electrode armband that measures a number of EMG signals related to wrist and hand movement. The EMG signals will then undergo amplification, filtration, and processing via a PCB. The processed EMG signal will then be inputted into a MATLAB program that relates EMG signal measurements to a set of movements. Finally, a wooden, prosthetic hand will demonstrate the movements as defined by the MATLAB program.

The key advantages of our modular design is universal compatibility and minimal costs. Creating a sEMG device that can be used across different prosthetics allows patients to select new prosthetics and prosthetic parts for replacement and repair without compromising functionality. Furthermore as prosthetic-users change their prosthetics over the course of their lifetime, especially among children, buying an entirely new prosthetic would no longer be necessary with our design. Rather, a prosthetic-user only needs to buy and replace the mechanical component of a prosthetic, saving them thousands of dollars in the long-run.

1.3 Visual Aid

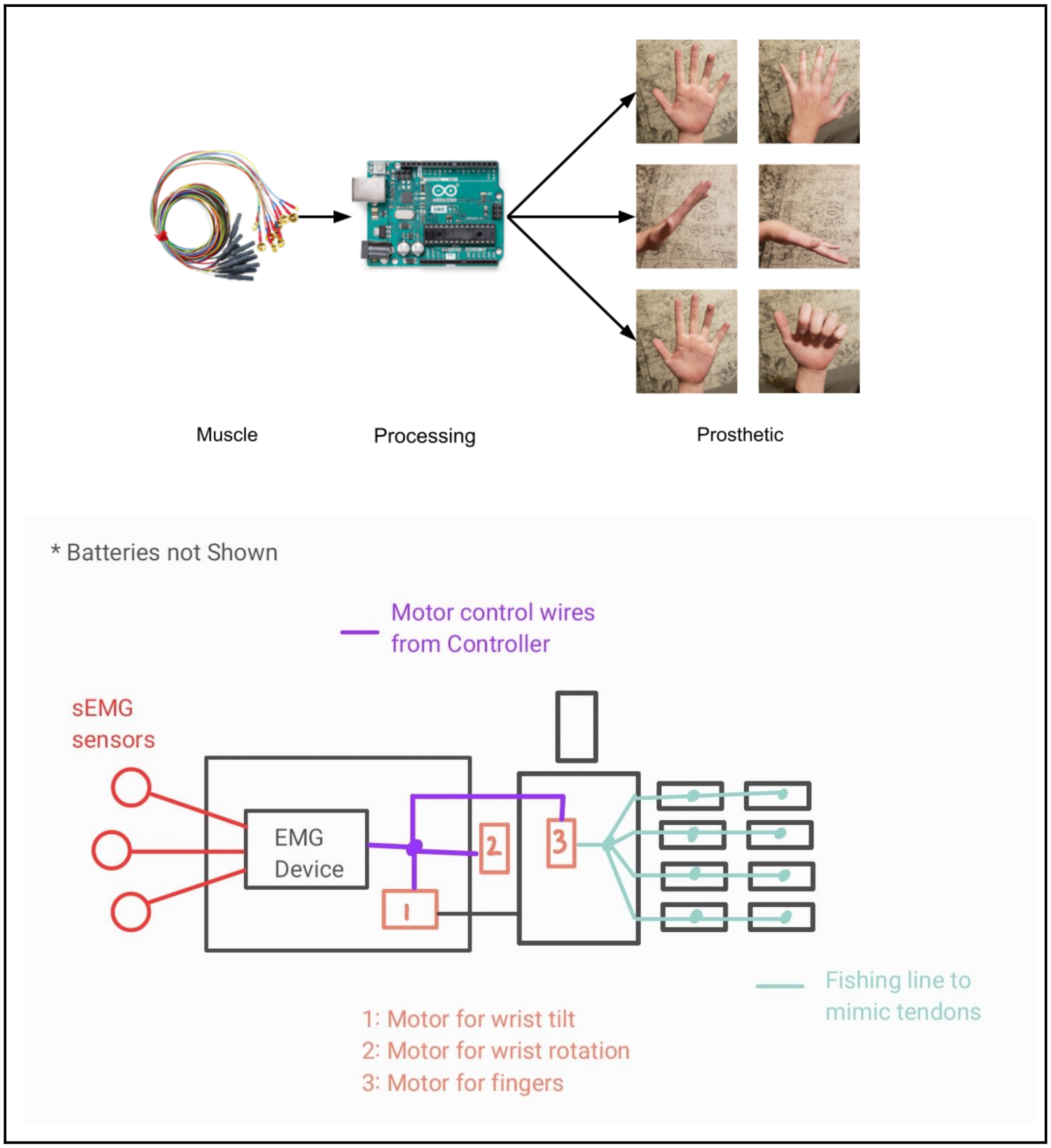

Figure 1.1 High level visual aid

1.4 High-Level Requirements List

- EMG device must be able to return to neutral orientation within 15 degrees of initialized position after at least 10 prosthetic movements.
- Prosthetic arm should mimic digit extension/flexion with at least 70% accuracy.
- EMG device must be able to operate with at least 2 unique subjects

2. Design

2.1 Block Diagram

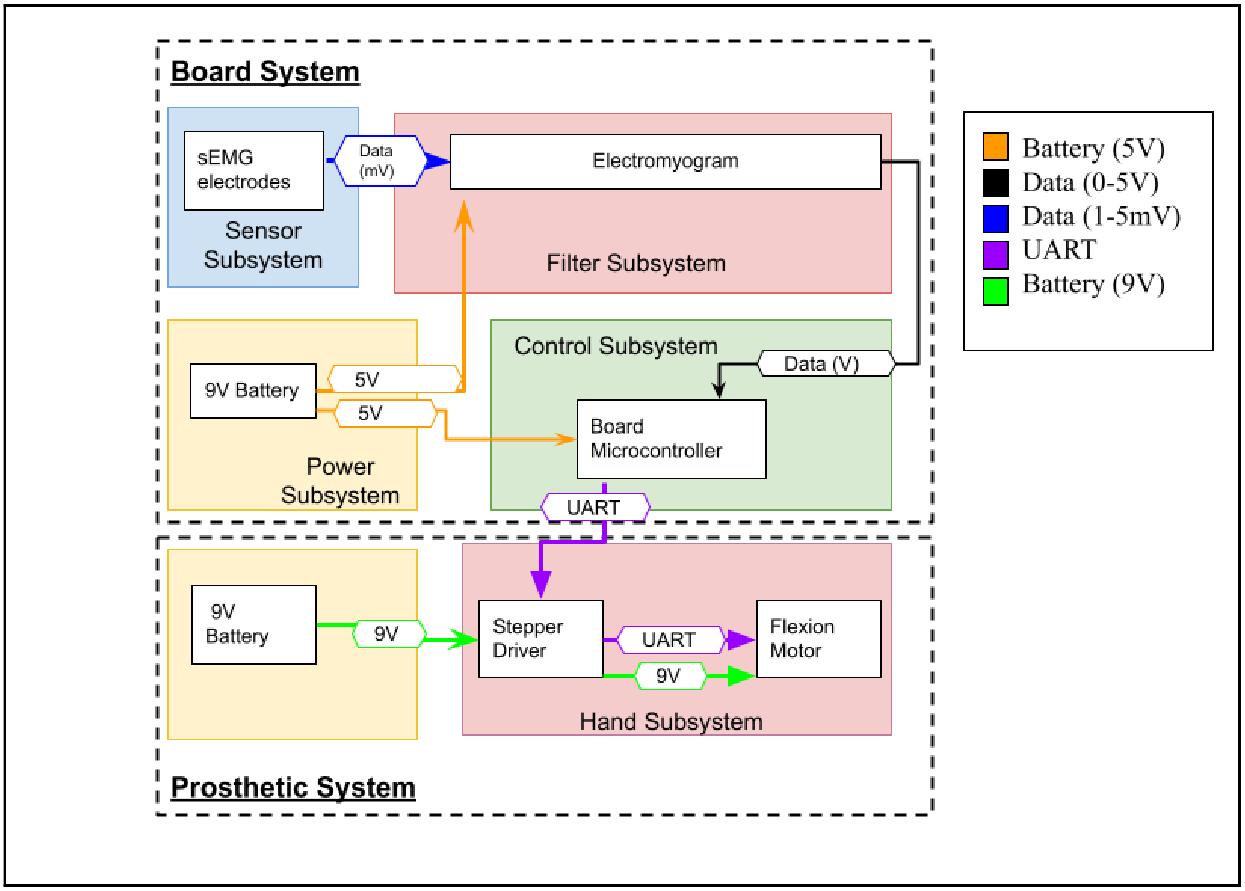

Fig 2.1 Block diagram for EMG device and prosthetic hand

2.2 Subsystem Overview and Requirements

2.2.1 Board System

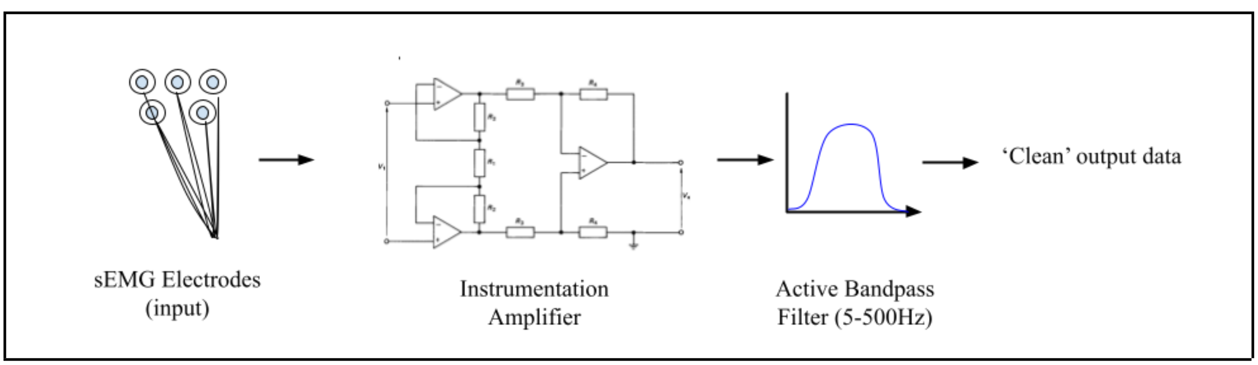

Fig 2.2 Data pipeline for the EMG device

Sensor

The sensor system serves to acquire the sEMG signals of the muscles used for digit flexion, digit extension, supination, pronation, wrist abduction, and wrist adduction. This system will be implemented as a wearable arm band consisting of 6 panels of copper sheet metal. The 6 copper panels will be oriented along the longitudinal midline of the muscles and will measure the raw EMG signal that is sent to the EMG PCB for signal processing.

Requirement 1: Copper panels should be able to measure EMG signals with amplitudes between 0 - 2000 uV.

Requirement 2: Size of electrodes are less than or equal to 10mm.

Requirement 3: Distance between copper panels should not be less than 20 mm.

Filter

The filter system receives the raw EMG signal from the sEMG electrodes and amplifies, filters, and rectifies the EMG signal for signal processing. A differential amplifier will be used to suppress the common baseline noise due to inherent noise of the electrode, movement artifacts, electromagnetic noise from the environment, and internal noise from physiological factors like body fat [8]. Since the EMG signal is very weak with amplitudes ranging from 50 uV - 2,000 uV, the differential amplifier will also accomplish an ideal gain between 100 V/V - 10,000 V/V [12]. Upon amplification, the EMG signal will pass through a bandpass filter constructed from capacitors and resistors. Filtering the measurements that are outside the range of an EMG signal, the bandpass filter will specifically have a low cutoff frequency of about 5 Hz and a high cutoff frequency of about 500 Hz [11]. The amplified and filtered EMG signal will then undergo a full wave rectifier to ensure the average of the AC EMG signal is not zero and finally be input to the board microcontroller for interpretation to prosthetic movement.

Requirement 1: The gain of the differential amplifier should be 5,000 V/V ± 1,000 V/V.

Requirement 2: The bandpass filter must have a low cutoff frequency of 5 Hz ± 5 Hz and a high cutoff frequency of 500 Hz ± 5 Hz.

*Requirement 3:*Should supply at least 500mA continuously at 5V +/- 0.1V to the microcontroller.

Power(s)

A 9V battery will be used to power the EMG device. This will ensure that the filtering components as well as the microcontroller get enough power. The battery will need to be adjusted before being fed to the various components. The microcontroller needs 5V while the operational amplifiers require between 2.7V and 5V. The instrumentation amplifier requires at least 2.25V. The battery on their own may overload some of the components so a voltage regulator circuit will be built to step down the voltages appropriately

Requirement 1: The board power system must be able to provide 5V and 250mA to the microcontroller.

Requirement 2: The board power system must be able to provide 2.5V +/- 0.3V with current at 1.7 - 2.8 mA.

Another 9V battery will be connected to the prosthetic device to ensure continuous motor power. Only one motor will be activated at a time to minimize the load on the battery. The voltage will also need to be stepped down to meet the specification of the motors (5V). While the power comes from the battery, the signal to turn the motor will come from the control subsystem.

Requirement 1: The prosthetic power system must be able to provide at least 5V and 200mA to each motor when needed.

Control

The control unit will consist of the Arduino UNO that receives the processed EMG signal from the EMG PCB. Defined voltage thresholds of an EMG signal from a particular muscle correspond to certain hand and wrist movements. The Arduino UNO will be programmed such that the voltage measurements of the EMG signals which exceed these defined voltage thresholds correspond to certain hand and wrist movements. Then the microcontroller will send the appropriate signals to the motors to move the prosthetic in the correct manner.

2.2.2 Prosthetic System

Hand

The prosthetic hand system is made by connecting a stepper motor to a wooden model of a hand. The motor will be used to move the fingers to open or closed positions based on the signal from the controller. The hand and motor system will be physically separate from the board system, which remains attached to the controlling muscle.

Requirement 1: The hand must be able to move to the correct position in under 2 seconds with 90% accuracy.

Requirement 2: The motors must return the prosthetic hand within 15 degrees of the initial orientation after 30 successful prosthetic movements.

2.3 Tolerance Analysis

The filter subsystem of our design poses a risk to successful completion of the project. Proper filtering of the EMG signal by the bandpass filter is critical to suppress noise, prevent artifact contamination, and ultimately preserve the EMG signal of interest. Loss of information about the EMG signal due to improper filtering will result in not only inconsistency in EMG signal readings but also improper movement of the prosthetic. To ensure our project is still feasible with this risk, we will calculate the resistor and capacitor values of the bandpass filter to ensure the cutoff frequencies of the bandpass filter is appropriate for our EMG signal. The expected range of data from the sEMG sensor is between 5 and 500 Hz. Using equation 1, we can determine the necessary resistor and capacitor values for the high and low pass filter. With a lower cutoff frequency of 5Hz and upper cutoff frequency of 500Hz, the following resistor and capacitor values have been calculated (note this is one of infinitely many possible values):

Given the high-pass filter circuit schematic in figure 2.3.1 and a desired high-pass filter cutoff frequency of 5 Hz, we can determine the resistor and capacitor values using the following equation 1.

$$2 * \pi * F = \frac{1}{R*C} \qquad \text{Eq 1.}$$

Where F is the desired cutoff frequency

$2 * \pi * 5Hz = \frac{1}{R*C}$

$31.42 = \frac{1}{R*C}$

If

Resistor = 320,000 Ω

Capacitor = 100 nF

Then

High-pass filter cutoff frequency = 31.25 / 2π = 4.97 Hz

Percent Error = $\left|\frac{4.97 - 5}{5}\right|$= 0.53%

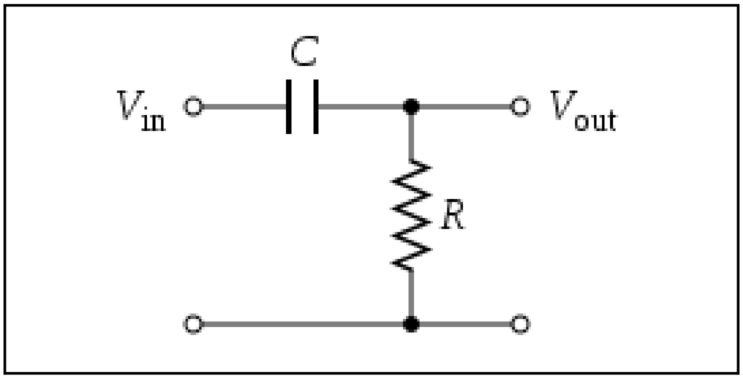

Fig 2.3.1 High-pass filter circuit schematic

Given the low-pass filter circuit schematic in figure 2.3.2 and a desired low-pass filter cutoff frequency of 500 Hz, we can determine the resistor and capacitor values using the same equation.

$2 * \pi * 500Hz = \frac{1}{R*C}$

$3142 = \frac{1}{R*C}$

If

Resistor = 3,200 Ω

Capacitor = 100 nF

Then

Low-pass filter cutoff frequency = 3125 / 2π = 497 Hz

Percent Error = $\left|\frac{497 - 500}{500}\right|$= 0.52%

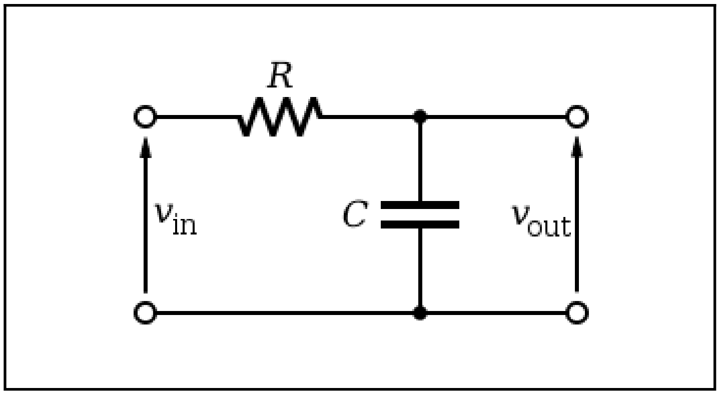

Fig 2.3.2 Low-pass filter circuit schematic

Granted the low percent errors of our low-pass filter and high-pass filter are both 0.51%, we can ensure the bandpass filter is precise enough to only allow the EMG signal from the desired range of 5 Hz - 500 Hz to pass.

3. Ethics and Safety

We recognize the importance of technologies and their capability to affect lives throughout the world. Thus, we agree to commit ourselves to follow the Code of Ethics adopted by the IEEE and uphold the highest standards of integrity, responsible behavior, and ethical conduct with making the Affordable Universal Controller for Upper Limb Prosthetics.

I. **We will not store nor share any patient data as to protect the privacy of others and to prevent any conflicts of interest [13].**

   With online privacy becoming a bigger concern in recent history, we will ensure that no personal information is saved. This is not only ethical but also aligns with the strict Illinois privacy laws. By not storing information, we will also not be able to sell any data as a way to fund the project.

II. **We will accept criticism of our work, and be honest in stating claims or estimates regarding our device [13].**

   The design and building process will reveal flaws in our system and talking to more experienced people, they will provide feedback and offer suggestions. We will accept all criticism and tweak our design to mitigate any weaknesses or oversights on our part. When testing and verifying our system, we will be truthful with the data and include all relevant results, even one time outliers as a part of the analysis in the capability of our design.

III. We will treat all persons fairly and strive to ensure the code of ethics is upheld by colleagues [13].

We acknowledge that we all come to this group with different skills and it will take our combined efforts to create a successful project. We will divide workloads fairly to each member, taking into consideration what they specifically excel at. We will be kind to each other and all persons that we may interact with. We will also be each other witnesses to make sure that the code of ethics is followed and respected.

IV. We hold paramount the health and welfare of the public [13]

The prosthetic controller will be made affordable with the idea that all people who can benefit from a prosthetic will be able to receive them without the burden of heavy costs.

Safety

One of the most dangerous parts to our design is the battery. They are dense in energy and if used improperly, they could lead to explosions or severe burns. We will minimize the chance of injuring others by using dry cell batteries instead of a lithium ion battery as the device will be attached to the user. Lithium batteries may overheat and burn the user or even catch fire and cause even more severe injuries. Dry cell batteries are not immune to these issues but greatly decrease the risk of such accidents. To further increase the safety of our design, we will also ensure the batteries cannot be short circuited in any case which prevent excessive wear on the battery.

We will also avoid using motors that are more powerful than necessary. The prosthetic hand will be close to the user and powerful motors could tear the build apart in the event of malfunction and injure people around it. As our project will only be for demonstration purposes, we will use weaker motors that can move the necessary components but are not powerful enough to break any other components or cause harm to any body parts.

Our design utilizes low voltages and although the sensors are located on the person's arm, there is no other interaction that may cause serious dangers. The sensors are made of copper which is harmless and overall, our design includes minimal safety concerns. Every member of the group has completed the safety training and therefore is knowledgeable in appropriate behaviors in the lab and interacting with equipment, electronic components, and colleagues. Every member is also trained in how to act in the case of possible emergencies.

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