Project Proposal

Pressure Detection: Improving Prosthetics Efficacy

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ECE 445 Fall 2017

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Section 1: Introduction

1.1: Objective

As able-bodied humans, we often take for granted our ability to perform basic physical actions such as walking and picking up objects with our hands. Unfortunately, for many people around the world, freeform body movement is something that exists only in dreams and the imagination. For example, in the United States, 16.3% of adults have some kind of physical functioning difficulty [1]. In many cases, engineering principles- including those of electrical and computer engineering- can be used to improve the lives of the disabled. One particularly important disability to address is the loss of arm function due to amputation. In the United States, 41,000 people have suffered the loss of a hand or a complete arm [2]. Engineering has attempted to address this problem with a prosthetic upper limb- however, there are issues with current implementations, namely efficacy and high cost.

One of the major challenges in designing a prosthetic upper limb is the effectiveness of the sensing method that collects biological signals from the patient's upper arm or shoulder and maps them to various hand and wrist movements. The traditional sensing method for this purpose is surface electromyography (sEMG) [3]. However, this method yields inconsistent results in practical use due to the fact that the sEMG electrodes oftentimes capture a noisy mixture consisting of several arm muscles [4]. Several researchers have demonstrated that, when attached to the arm, an array of tactile pressure sensors can be used to capture muscle bulges and infer the patient's desired wrist and hand movements [4]. Therefore, a pressure sensor array should be considered as a viable input mechanism for a prosthetic arm.

Our objective is to design and build a system to perform intent classification in a prosthetic arm. Our system will use a pressure sensor array to replace the existing sEMG-based sensing solution. The system should integrate cleanly into the prosthetic arm developed by Psyonic, as described below.

1.2: Background

Psyonic is a local startup that is developing an affordable prosthetic hand for people with upper-limb amputations. Currently, they have a completed and working product that uses electromyography (EMG) to enable the patient to operate the hand. However, they face several obstacles in the prosthetic-arm interface. One of their main challenges is that the EMG signal incurs a lot of noise from many sources, such as high impedance of the skin, external shock, shifting of the arm, sweat, and more. This results in unintended movement of the prosthetic fingers. After communicating with the Psyonic team, we believe that we can overcome many existing obstacles by replacing the existing EMG model with a model based on pressure sensing.

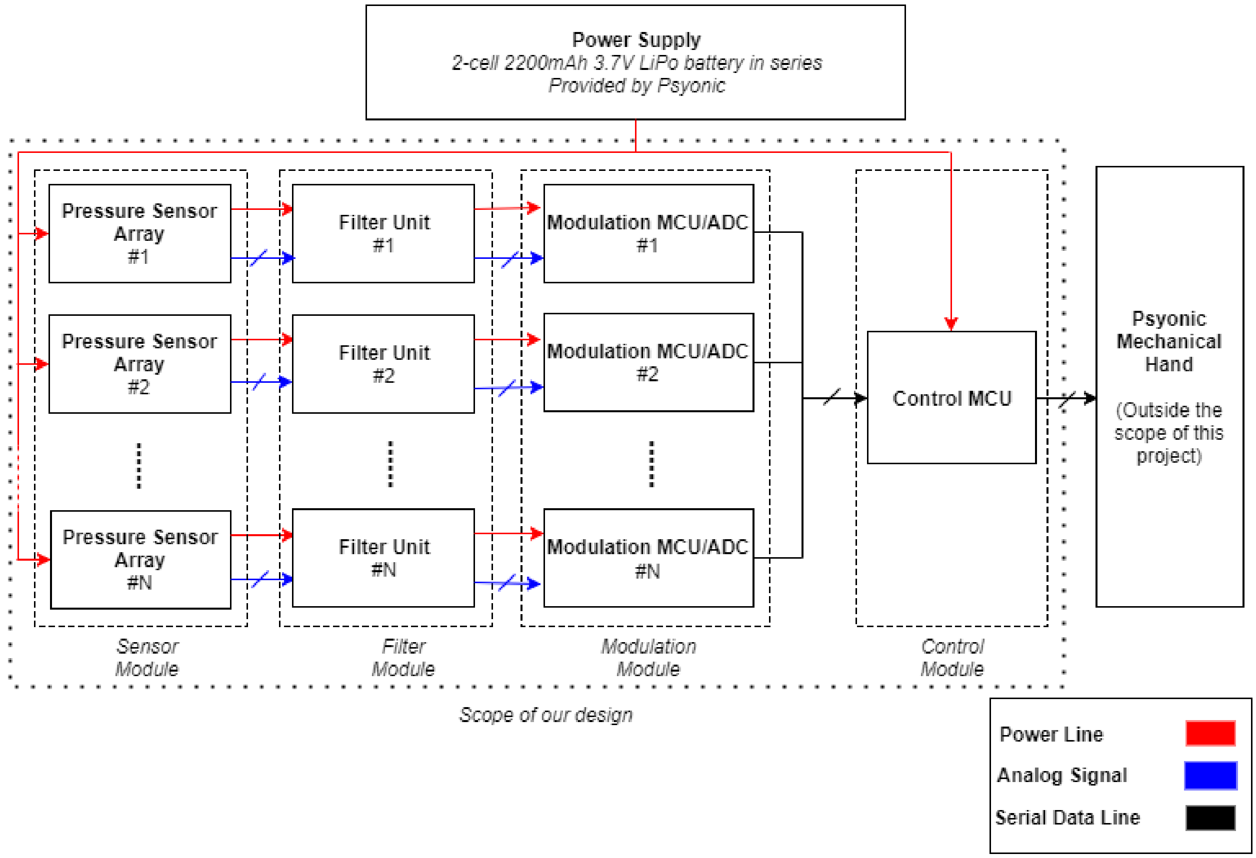
Psyonic aims to provide an affordable prosthetic hand that will entail no out-of-pocket cost to patients with health insurance [5]. Given this, the components we choose will need to be as inexpensive as possible while still fulfilling their intended purpose. For example, the microcontroller that runs the classification algorithms will need to be small-scale and low-power, yet still powerful enough to run the algorithms.

1.3: High-Level Requirements List

- The hardware component (i.e. the circuitry to collect, process, and store the pressure sensor inputs) should deliver the inputs with as little noise as possible.
- The hardware component should store the collected data, allowing the microcontroller to easily sample the values.
- The microcontroller should execute code to interface with the hardware component and run classification algorithms, mapping the patient's input to one of several hand gestures in real time.
- The machine learning model must classify the intensity map patterns read from the pressure sensors, outputting a set of hand/wrist movements. Training should be done on a per-person basis.
- Our design needs to integrate with Psyonic's existing prosthetic arm design; therefore, the microcontroller will need to communicate with actuators according to Psyonic's protocol.

Section 2: Design

2.1: Block Diagram



We believe that our design will satisfy our high level requirements. By analysing and filtering the data from arrays of pressure sensor, we can minimize the noise and increase the classification accuracy. The microcontroller we are going to use, stm32f401rbt6, has adequate processing power to run the classification algorithm, ensuring low latency. Since we are implementing this module as a part of the bionic arm for Psyonic, we will be working closely with them to ensure that our module will fit in the housing and that our MCU will follow existing communication protocols.

2.2: Physical Design

Since our design will be integrated into Psyonic's existing prosthetic arm design, most physical design aspects are beyond the scope of this class. We just need to ensure that the array of pressure sensors can be placed in a ring formation that will fit around a human forearm and be portable. As such, no physical design diagram will be provided.

2.3: Functional Overview and Block Requirements

The hardware component needs to convert the analog signals from the pressure sensors to digital signals and ready them for processing by the microcontroller. This will involve operational amplification, sampling, quantization, filtering (to reduce noise), and likely storage in registers. Since the PCB needs to successfully integrate into Psyonic's existing product, it has to satisfy a number of constraints. First, it needs to be small enough to easily fit into the prosthetic casing. It also has to run efficiently in the low-power environment used in their current product. Finally, it will need to be able to read data from a large number of pressure sensors, as many will be required to produce useful and classifiable data.

2.3.1: Pressure Sensor Array

The pressure sensors must provide high (approximately 5 mm) spatial resolution in their measurements. This is necessary in order for the machine learning algorithms to have a good idea of where the pressure is being applied. On the other hand, the pressure sensors do not need to provide incredibly high accuracy- an accuracy of around $\pm 2\%$ will do. Koiva et al. shows that standard deviation of RMSE of the predictions for each movement class pattern is significantly lower than the 2% inaccuracy [4], thus the prediction will likely not be affected. Indeed, high spatial resolution may only be achievable with certain cost to accuracy.

Requirement #1: Pressure sensors must provide approximately 5 mm spatial resolution.
Requirement #2: Pressure sensors should provide roughly $\pm 2\%$ *accuracy.*

2.3.2: Filter Unit

The filter unit must remove or alleviate environmental noise introduced into the analog signals coming from the pressure sensor array. However, without thoroughly testing and characterizing the signals from the sensors we choose to use, it is difficult to tell what types of noise may be introduced. Therefore, it is difficult to say whether a low-pass, high-pass, or bandpass filter will be needed. Depending on the results, the filter unit may not be necessary at all.

Requirement #1: The filter unit should alleviate environmental noise while not adversely affecting the pressure sensor requirements in 2.4.1.

2.3.3: Modulation MCU/ADC

This block consists of an analog-to-digital converter to render the pressure sensor signal usable for processing, and a small-scale microcontroller to sample and store the data for the pressure sensor array to which it is assigned. The two are in the same block because they will most likely be present on the same chip. Each array will contain 16 pressure sensors- therefore, the microcontroller will need to have at least 16 user-accessible registers in which to store these values. The microcontroller will also need to have an output serial line with which it can communicate with the main microcontroller. Furthermore, the sampling microcontroller will likely need to run at least 1 MHz in order to sample and store the data in line with the ADC's sampling frequency, which will need to be at least two times greater than the largest notable frequency in the pressure sensor frequency spectrum, as dictated by the Nyquist criterion. However, given the simplicity of the operation it's performing, the sampling microcontroller does not need to run an operating system, nor does it have any particular memory requirements.

Requirement #1: The ADC's sampling frequency needs to be at least two times greater than the largest notable frequency in the pressure sensor frequency spectrum.
Requirement #2: The sampling microcontroller needs to have at least 16 user-accessible registers.
Requirement #3: The sampling microcontroller needs to run at least 1 MHz.
Requirement #4: The sampling microcontroller needs to have an output serial line.

2.3.4: Control MCU

The Control MCU acts as the central control unit for the system. It handles the training and prediction phase of the classfication model for the movement classes. The Control MCU will first read pre-processed pressure sensor data from the registers of each modulation MCU. For the training phase, the MCU will generate binary decision boundaries based on the average pattern for each movement class observed. In prediction phase, the prediction goes to the movement class with the highest prediction confidence with respect to each binary classification boundary. Also the classification result must be translated and transmitted via serial data line so that it meets the requirement of the existing interface of the Psyonic robotic hand.

Requirement #1: The control microcontroller must be clocked at at least 20MHz
Requirement #2: The control microcontroller must be able to handle 32-bit float point calculations
Requirement #3: The control microcontroller must be have an output serial line

2.4: Risk Analysis

We believe that the portion of our project that will cause us the greatest difficulty and pose the greatest risk of failure is the pressure sensor array. This is because the efficacy of the pressure sensors is highly dependent on their physical placement in the ring formation. Depending on the person using the device, the pressure sensors might not deliver the exact same results that were observed in laboratory-setting tests. This means some calibration will be required. Also, results will depend on the quality of the foam placed over the tactile sensors. We will need to perform tests with a few different kinds of foam and determine which is best. Finally, we will need to deduce what kinds of noise may be introduced into the signal from the pressure sensors. Overall, since the pressure sensors are the most novel part of our project, they are also the most prone to risk. However, the improvements they bring over EMG should make it worth the effort!

Section 3: Ethics and Safety

3.1: Wearable Medical Device Concerns

In designing and building our system, we must remain cognizant of potential ethical issues surrounding the process. Since our system is meant to be used in a wearable medical device, we must be especially attuned to the first tenet of the IEEE Code of Ethics: “to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment” [7]. Due to the importance of the arms in daily life, we are ethically obligated to do everything in our power to ensure that our design is effective, safe, and comfortable for the user. We are also ethically motivated to keep parts costs as low as possible, so that the design will be accessible to those in need regardless of economic status. Thankfully, since we’re integrating with Psyonic’s existing design, they will be able to help verify that our design meets these requirements. Finally, it should be noted that, unlike more costly bionic limbs such as i-limb [8], our design will not feature bluetooth connectivity or an associated mobile app. This means that we will not have to contend with computer security concerns and related ethical dilemmas, as hackers will be unable to modify the operation of the arm without direct access to the hardware.

3.2: Battery Concerns

Lithium-ion based batteries are volatile by nature, and they can catch on fire or even explode if not charged properly or exposed to extreme temperatures. Overheating of the battery can be caused by an internal short circuit due to contaminants introduced in manufacturing [9]. However, these events are fortunately rare- the worst failure rates experienced (i.e. the ones that trigger device recalls) are generally around one in 200,000 [9]. Since we are not creating the power circuits as part of our project, we will work closely with Psyonic to make sure that the existing power circuit conforms to safety standards. Our team and Psyonic will also ensure that the specific batteries used in our prototype have no defects and work properly.

References

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