Muscle Fatigue Interface

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Abstract

Our senior design a devices that allow fitness enthusiasts to visually track their fatigue as they perform specific exercises. Such a device can aid in determining how effective their exercise is, prevent overtraining, as well as aid in muscular rehabilitation process, physical therapy, and research. Our final product was intended to be an inexpensive, transportable, and easy to maintain device that accomplishes these tasks and can store and port accumulated data. Due to several factors throughout the semester, our group had to compromise our central data processing unit (an Arduino Microcontroller which turned out to be unfit for our required metrics) to make our analysis portable and defaulted to our contingency plan of fully developing the processing software in LabView while interfacing our hardware directly with a computer running the LabView executable.

By the end of our development cycle, we had a successful implementation of our design that performed as we expected according to the biological research data available, however, portability & convenience of use were compromised within our contingency plan.

Below, the reader can find a summary of our progress throughout the project and more detailed information about the development of the Muscle Fatigue Interface, the challenges faced when engineering it, and the solutions our group used to mitigate problems & release a working prototype of our initial design.

Contents

1. Introduction

1.1 Statement of Purpose

This project was chosen because there presently are no devices that allow fitness enthusiasts to visually track their fatigue as they perform specific exercises. Such a device can aid in determining how effective their exercise is, as well as prevent overtraining. Knowing this information, one can program their rep/set scheme accordingly and thus increase the effectiveness of their workouts. Moreover, there are many other biological applications including rehabilitation, physical therapy, and research. We have chosen to focus on the modularity of the device to make it inexpensive, transportable, and easy to maintain.

1.2 Introduction to EMGs

When muscles skeletal muscles contract, the number of motor units increases and the frequency of motor units firing increases[4]. When a motor unit, or motor neuron, fires, the nerve contracts the muscle fiber. An action potential is transmitted across the neuromuscular junction and into the muscle fibers. This causes an increase in electric potential which can be detected on the surface of the skin with surface electromyography (EMG). The activity of several motor units can be collected through the EMG. Depending on the size of the muscle, the electric potential from the muscle will be around 200-300μV. Muscle fatigue is defined as a decrease in tension and power production caused by insufficient oxygen, depletion of energy, and the buildup of lactic acid. A decrease in pH of the muscle causes a decrease in the conduction velocity of the muscles which subsequently leads to a decrease in peak twitch tensions and an increase in contraction times[4]. This all leads to a decrease in median power frequency of the EMG signal, which our system uses as the indication of fatigue.

1.3 Functions and Features

This product will provide the following functions:

- Instrumentational amplifier and filters to reduce artifacts in the EMG signals for accurate tracking
- Analog to digital converter that also timestamps and stores the digitized information
- Easy and intuitive interface
- Fail Meter

1.4 Blocks and Modules

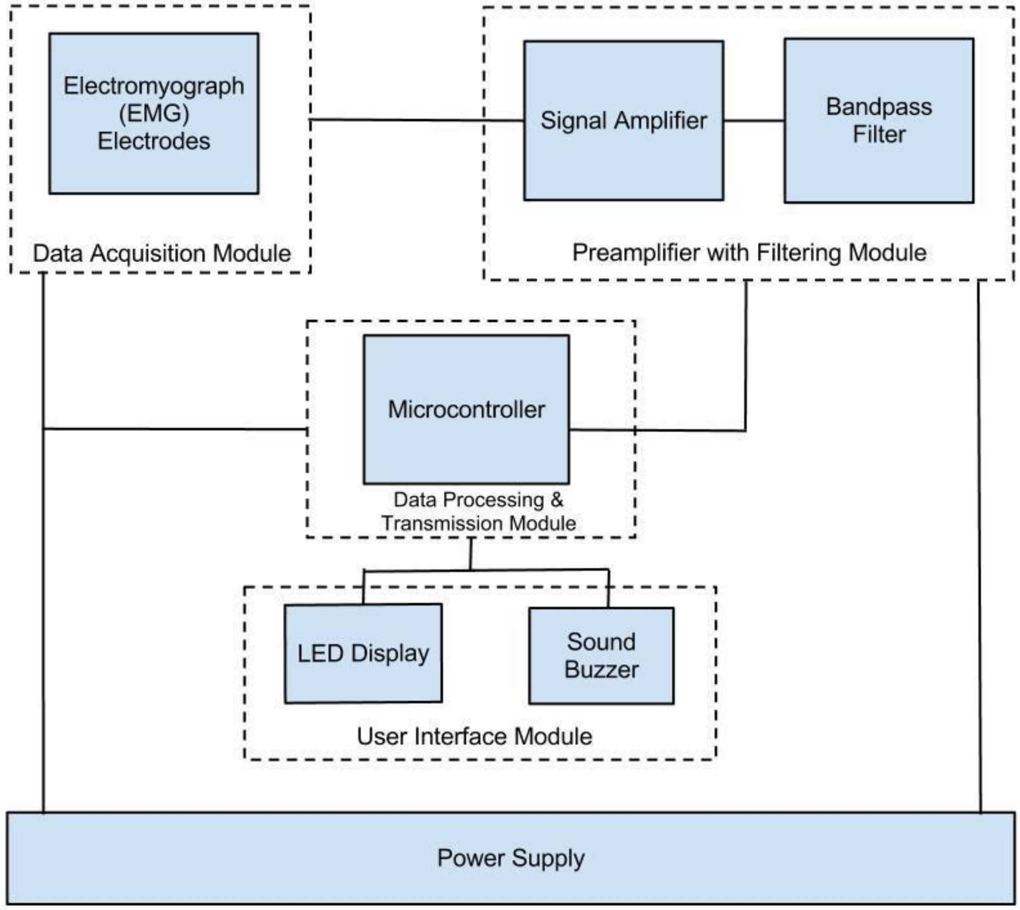

Figure 1.4 Overall Block Diagram

1. **Data Acquisition Module:** This module obtains the electrical activity produced by skeletal muscles during exercise by using Electromyography (**EMG**) to detect changes in the electrical potential generated by muscle cells via surface electrodes.[1] As muscular contractions are sustained, the spectrum of the electric signal shifts to the left (lower frequencies) as the firing rates of most motor units decreases, and the action potential of a fatiguing muscle attains a distinctly different shape than that of a fresh muscle (force twitches of motor units increase in amplitude during sustained contractions).[2]
   a. **Electrodes:** The electrodes will serve as the transducer that will capture the muscle's motor unit action potential (MUAP) and form our signal to be analyzed.
   b. **Attachment Armband:** The armband will be used to hold the electrodes in place while the user is exercising.

2 **Preamplifier with Filtering Module:** Since the peak amplitude of the signal picked up by the electrodes is usually in the range of 50μV - 1mV [3] (although 20-30 mV are not unusual, depending on muscle) we will need to amplify the signal to be able to analyze it. Furthermore, EMG signals are characteristic of having a bandwidth range from 0 to 500 Hz[4] ; using a bandpass filter, we are able to eliminate noise from our amplified signal and have accurate measurements with no outliers.

   a **Signal Amplifier:** We will be using an op-amp to amplify the signal coming from electrodes.

   b **Bandpass Filter:** The amplified signal will go through another op-amp with a bandpass filter to filter out frequencies below 20Hz and above 500Hz.

   c

3 **Data Processing & Transmission Module**: This is the heart of the project. We will program a microcontroller that will analyze the analog signal coming in from the bandpass filter and perform the necessary calculations to be able to identify fatigue based on the median frequency of the EMG signal. Fatigue is described by a downward trend in median EMG signal. The module transmits the state of fatigue based on thresholds customized for the user around their baseline signals. The correct number of LEDs will light up corresponding to the state transmitted.

   a **Microcontroller:** We will be using a Labview compatible microcontroller that we can port Labview code to which will be able to correctly analyze the incoming signal.

   b **Wireless Transmission Unit:** This will communicate with a computer and transmit the analyzed data via bluetooth or wi-fi for logging and additional visualization.

4 **User Interface Module:** This module consists of the elements that will notify the user of their muscle condition. A variety of colored LEDs will visualize the fatigue over time, a buzzer will indicate over-fatigue & a timer will be running for the duration of the workout being logged.

5 **Power Supply Module:** Our power supply will consist of a 9 Volt source (a battery) that will be stepped down to the different voltages required by each module using DC/DC converters.

2. Design

2.1 Design Procedure

Below, we review our initial design decisions proposed in our design review. As mentioned in the introduction, our primary module that had to be re-designed when we were implementing it into our product was the brain that processes the incoming data: the Arduino.

We over-estimated the microcontroller and realized too late that it was not powerful enough a processor to satisfy our requirements. The alterations to our design are discussed in subsequent section and justified numerically.

2.2 Description of Modules

2.2.1 Data Acquisition Module:

<u>Electrodes:</u>

Inputs: Raw EMG pulses from muscle

Outputs: analog EMG signal

Description:

The two differential inputs are hooked up approximately an inch or two apart on the bicep. One is placed on the bulge on the bicep and another, an inch or two lower. Placing it on the bulge keeps away from tendons and other musculature. This is to establish the difference in voltage between the two points. The electrodes need to be close enough to be on electrically related tissue but not so close that there would be no difference in voltage. Because muscle fibers of motor units are distributed evenly, large muscle coverage is unnecessary. A reference electrode is placed on the shoulder and is connected to ground. As shown in Figure 1, it simply needs to be connected to electrically unrelated tissue. Before the testing, the user will wipe their tissue with alcohol to reduce excess noise and resistance from dirt and loose skin cells.

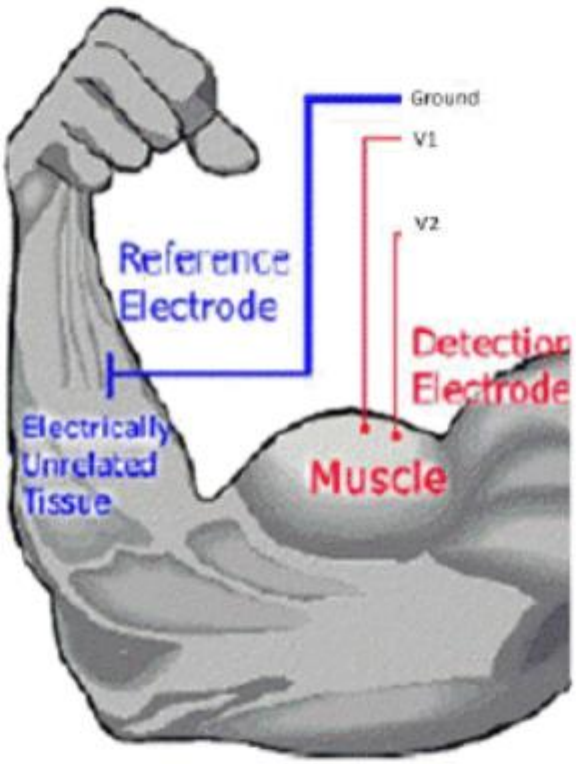

Figure 2.1: Representation of placement of electrodes on arm.[4]

2.2.2 Preamplifier with Filtering

AD622 Instrumentational Signal Amplifier:

Inputs: Raw EMG signal from electrodes

Outputs: Amplified raw EMG signal

Description:

The raw signal from the electrodes is first amplified by the AD622 instrumentation amplifier. This op-amp is able to measure a differential voltage on the skin and amplify it.It is quite effective in measuring the action potential of the motor neurons, reducing electromagnetic radiation, and allows for two electrodes. This chip is very easy to use and can be powered by a large range of power supply (+/-2.6V to +/-15V). It offers a good common mode rejection, a linear gain, and temperfature stability.

The gain can be changed by varying the resistor Rg as seen in table 2.2.3.1. We amplify the signal raw signal by about 50V/V using a resistance of 1.02K. The op-amp will also amplify any residual noise around the circuit. Hence, we require an additional bandpass filter to remove this noise. In addition, there will be protection circuitry in the form of diodes and capacitors which ensure that the inputs to the amplifier cannot be greater than their turn on voltage. Capacitors would provide low impedance paths for voltage spikes and the resistors to dissipate the energy in the form of heat.

Desired Gain	1% Std Table Value of Rg, Ω	Calculated Gain
2	51.1 k	1.988
5	12.7 k	4.976
10	5.62 k	9.986
20	2.67 k	19.91
33	1.58 k	32.96
40	1.3 k	39.85
50	1.02 k	50.50
65	787	65.17
100	511	99.83
200	255	199.0
500	102	496.1
1000	51.1	989.3

Table 2.1: REQUIRED VALUES OF GAIN RESISTORS

Bandpass Filter:

Inputs: Raw EMG amplified signal

Outputs: Filtered EMG amplified signal

Description:

The bandpass filter is built around the LM741 op-amp. It has overload protection built in and also has a good common mode rejection ratio. The bandpass filter will remove any outside noise and interference. Generally, 0-20 Hz is an unstable range indicating noise from the patient's motion, the electrode placement, or the electrode cord. Frequencies above 500 Hz are generally noise from RF interferences.[4] Thus, we require a bandpass filter ranging from about 20 to 500 Hz to reduce any noise that was amplified from the instrumentational amplifier. The bandpass filter will also have an additional gain of about 31V/V bringing the total gain of the preamp to 50*31= 1550V/V. Any more amplification tends to saturate the op amps. The resulting filtered EMG signal is then sent to the DAQ where it is then processed by the mock software/microprocessor.

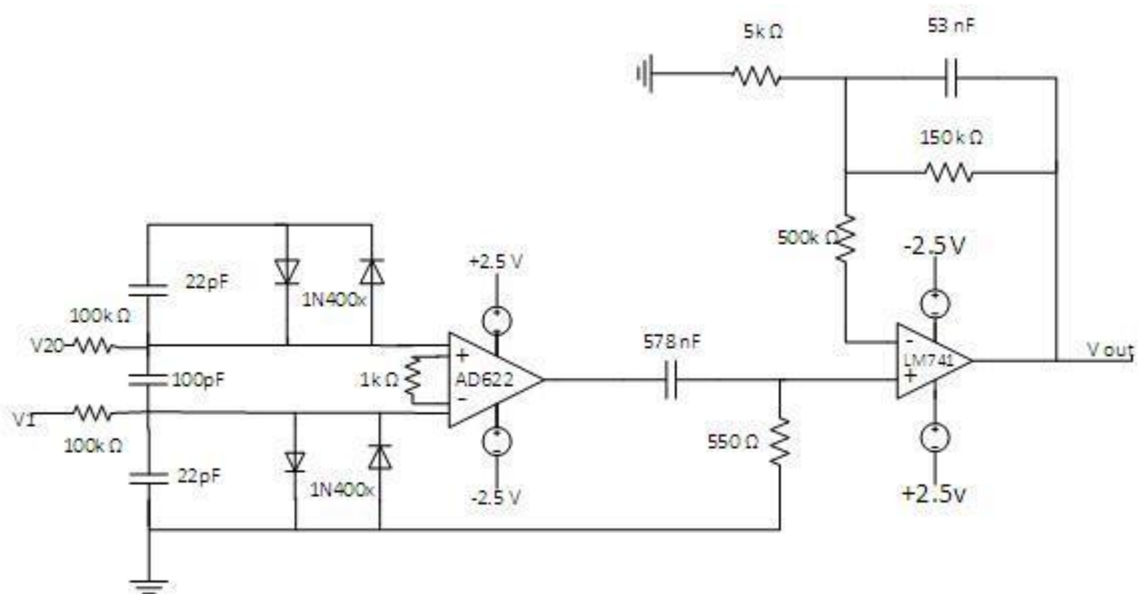

Figure 2.2 External Circuitry of the EMG Module

Low pass portion CL calculation:

$$\boldsymbol{Fl} = \frac{\mathbf{1}}{(\mathbf{2}\boldsymbol{\pi} \times \boldsymbol{RC_L})} \quad => \quad \boldsymbol{C_L} = \frac{\mathbf{1}}{(\mathbf{2}\boldsymbol{\pi} \times (\mathbf{150}\boldsymbol{k}\,\Omega)\,(\mathbf{20}\boldsymbol{hz}))} = \mathbf{53}\ \boldsymbol{nF}$$

High pass portion CH calculation:

$$\boldsymbol{Fh} = \frac{\mathbf{1}}{(\mathbf{2}\boldsymbol{\pi} \times \boldsymbol{RC_H})} \quad => \quad \boldsymbol{C_H} = \frac{\mathbf{1}}{(\mathbf{2}\boldsymbol{\pi} \times (\mathbf{550}\,\Omega)\,(\mathbf{500}\boldsymbol{hz}))} = \mathbf{578}\ \boldsymbol{nF}$$

Gain calculation

$$\mathbf{Gain} = \frac{\mathbf{1+150k}}{\mathbf{5}\boldsymbol{k}} = \mathbf{31}\frac{\boldsymbol{V}}{\boldsymbol{V}}$$

2.2.3 Data Processing & Transmission

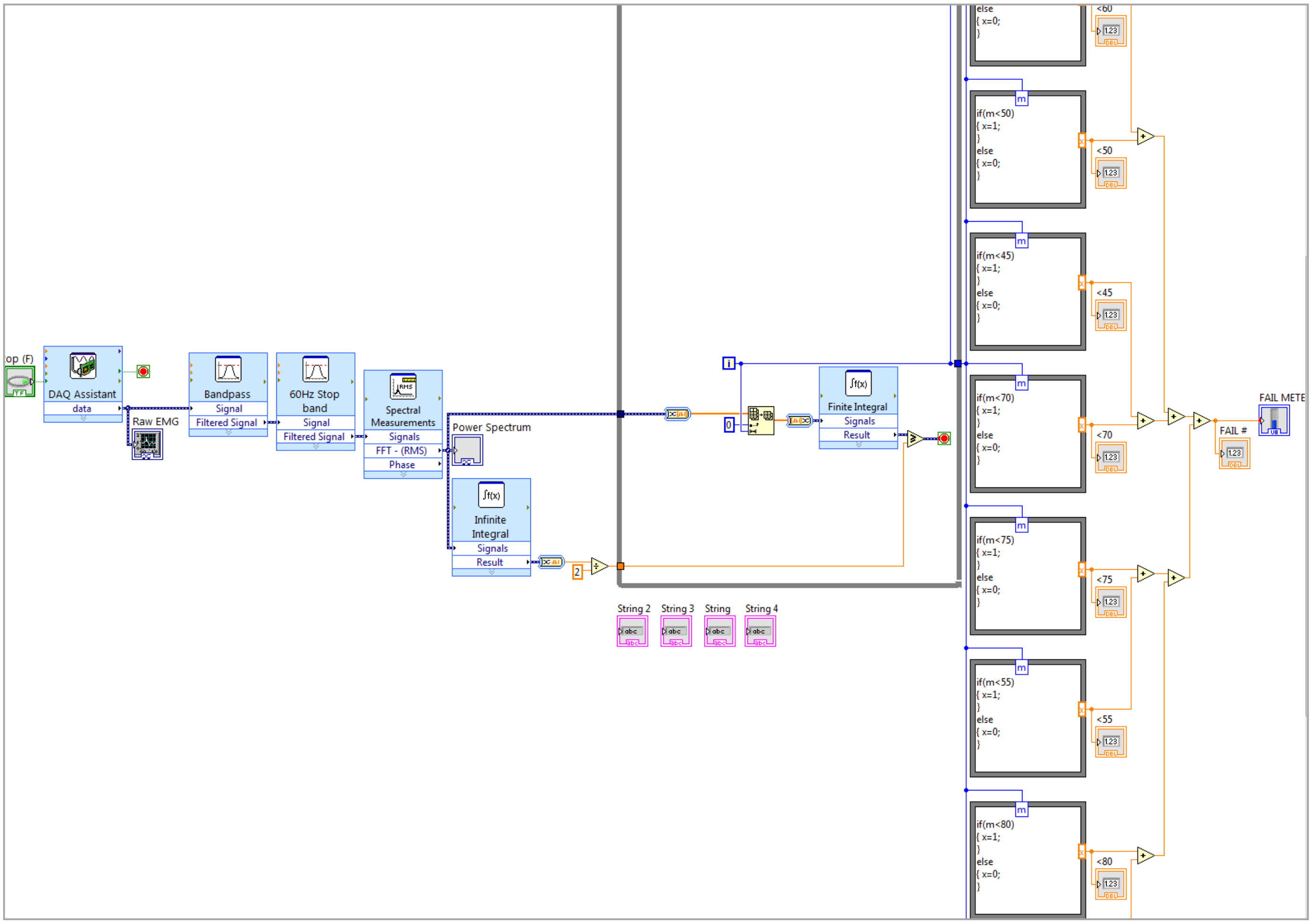

Figure 2.3. Labview code

Figure 2.3 shows the code written in Labview for signal processing, which we ended up using to substitute the microcontroller (more on this later). The data from the Data Acquisition module samples 2000 points at 2000Hz. The data is then sent through another digital bandpass filter with a low frequency cutoff of 20Hz and a high frequency cutoff of 500Hz. This second bandpass filter will act as a second order filter to ensure all unwanted frequencies are filtered out. The signal then goes through a bandstop filter which filters out frequencies 58-62Hz. Generally, 60Hz represents noise from the circuit and power lines.

Our system is essentially a third-order filter: one from the external circuitry, one from the Labview bandpass, and one from the Labview bandstop. After filtering the raw data, the square of the fourier transform of the data is taken. This represents the power spectrum - a range of frequencies and includes fast and slow motor units. The median frequency is then taken and graphed. The median frequency is the indicator of muscle exertion. A typical median frequency of the bicep will start around 80Hz and failure tends to happen at 50Hz. Of course, each person is different and thus the system will account for it in an initial calibration stage.

As part of the interface, we have created a Fail Meter, which is the software version of the fatigue indicator based on the median frequency. Based on experimental data, a range of the Fail Meter is created between 50Hz and 100Hz. Multiple ranges will be created in increments of 10Hz to feed into the Fail Meter which will update every at data point. The Fail Meter is a software representation of the LED's that will be implemented. Also, when the Fail Meter is almost filled, the beeper will sound.

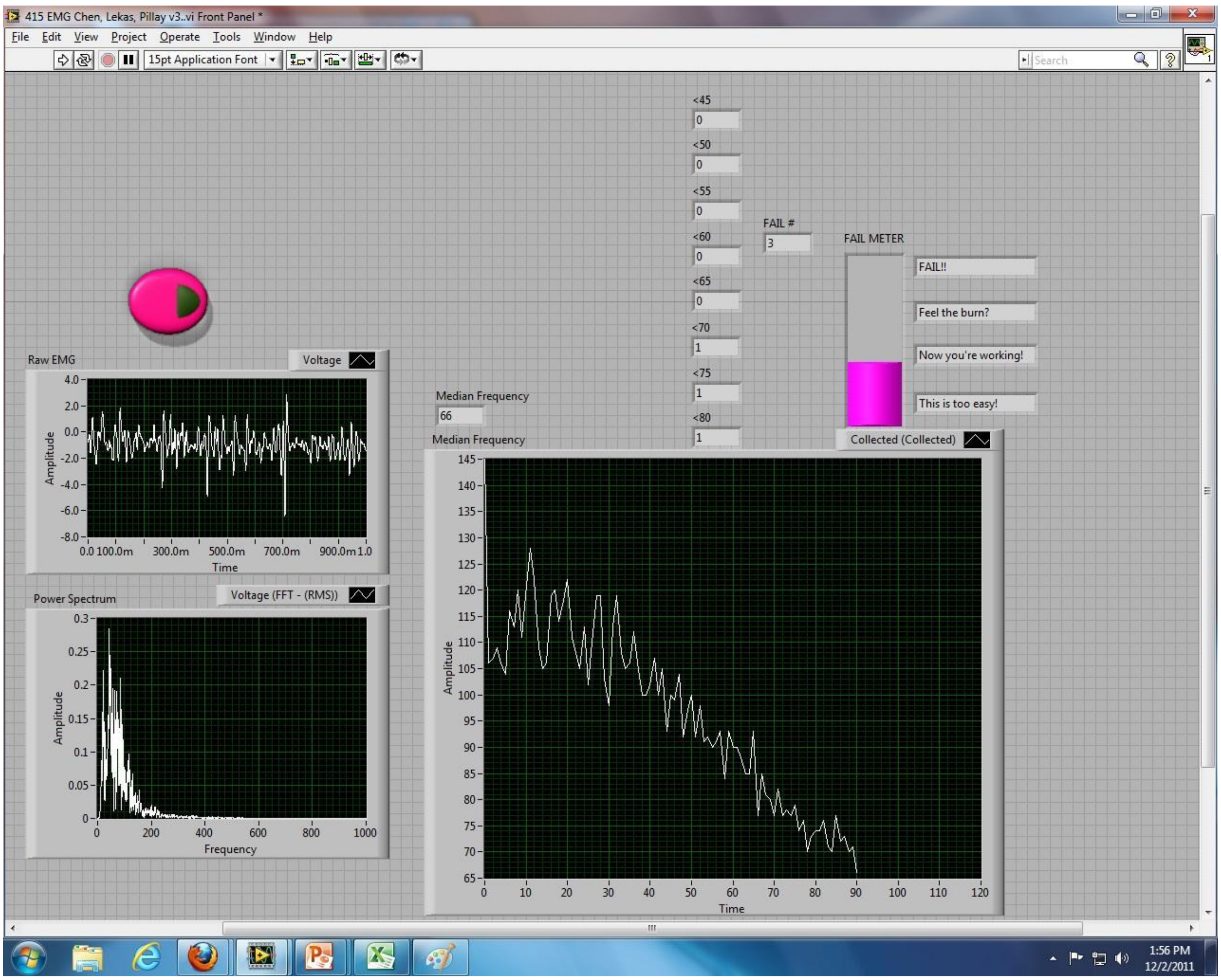

Figure 2.4 Full simulation of preamp + Labview code.

<u>Microcontroller:</u>

Inputs: Amplified signal from the Pre-amp

Outputs: Signals to LEDs, Signal to Sound Buzzer

Description:

The microcontroller will be used to process the signal coming from the filter part of the circuit. This will be connected to three additional components, that is, the LED display, timer, and the sound buzzer. The microcontroller will also calibrate the device based on the user, since each user has their own baseline signals.

For the microcontroller, we will be using the Arduino Uno R3 board. This is a relatively portable board and performs all the signal processing we will need to determine the user fatigue. It will take in the output of the hardware based filter as input and it outputs a signal to the LED's or the sound buzzer as necessary.

The microcontroller itself will take the input signal and will run a Fast Fourier Transform (FFT) on the given input. This will be implemented using the FFT library found on a tutorial website for the Arduino board. [6] The output of the FFT will be analyzed to get the frequency of the input signal as well as the amplitude. These values can then be used to drive the LED's depending on the range of values of amplitude and frequency as required. Additionally, the onboard XBee wireless interface can be used to wirelessly transmit data about the amplitude peaks onto a computer. This information can then be graphed to give a visual representation of a user's muscle fatigue.

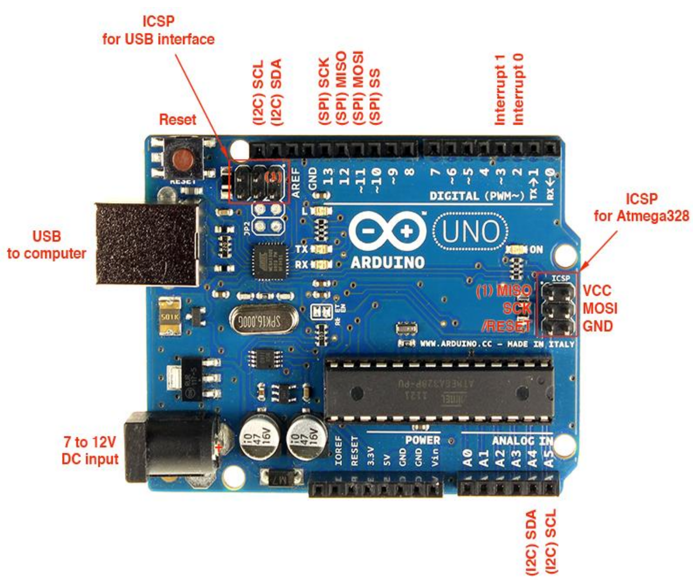

Figure 2.5: Arduino Uno R3

Wireless Transmission Unit:

Inputs: Signal from Arduino Board

Outputs: Wireless transmitter

Description:

The onboard XBee wireless interface can be used to wirelessly transmit data about the amplitude peaks onto a computer. This information can then be graphed to give a visual representation of a user's muscle fatigue.

2.2.4 User Interface Module:

LED Display:

Inputs: Signals to LED

Outputs: Visible feedback

Description:

The LED display will take its inputs from the microcontroller, and will give the user a visual representation of the amount of stress/fatigue that is being placed on the muscles.

Sound Buzzer:

Inputs: Signal to Sound Buzzer

Outputs: Aural feedback

Description:

Like the LED display, the sound buzzer too, takes its inputs from the microcontroller. The purpose of the buzzer is to give the user an additional source of stimuli in order to warn the user when their muscles are near failure. These parameters vary from person to person; however, the microcontroller will be calibrated per user.

2.2.5 Power Module:

Inputs: 9 volt battery

Outputs: power connections at specified voltages

Description: The power supply module is at the heart of powering the amplifiers with 9v input. We did not need to utilize the DC/DC step down converters for the microcontroller as originally planned and the range of the TTL amplifiers easily accommodates 9 V Vcc.

Device	**Voltage(s) Tolerances**	**Voltage Used**
LM741 Op-Amp	±22V	±9V
AD622 Instrumentation Amplifier	±2.6V - ±18V	±9V

Table 2: Voltage Requirements

Based on the Voltages we decided to use and the devices' maximum current draw, we expected a maximum energy drawn of 132.5 mW:

Power Consumption:
LM741 (Max) Power: 50mW
AD622 (Max): 1.5mA X 5V = 7.5mW
Arduino (Max): 25mA X 5V = 75mW
= 132.5mW

We used an Energizer 522 9 volt battery we can expect a life time of between 400 and 500 hours as indicated by the data sheet:

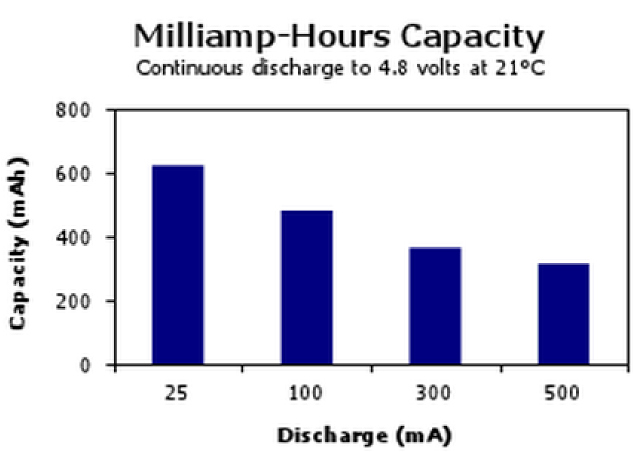

Figure 2.6 Energizer 9 V lifetime

3 Design Verification

3.1 Verifications

Refer to Appendix A.

3.2 Quantitative Results

Rates of fatigue for each subject remain in the same range which means that the system works because it is repeatable. The average rates of fatigue for each subject don't wildly differ from each other, there is only a 0.495 between the largest and the smallest rates of fatigue. The change in rate of fatigue goes down for three of the four of the subjects which is what one would expect. Subject 1's results were abnormal in that the change in rate of fatigue fluctuated, did not decrease, and the median frequency started much higher than the other test subjects.

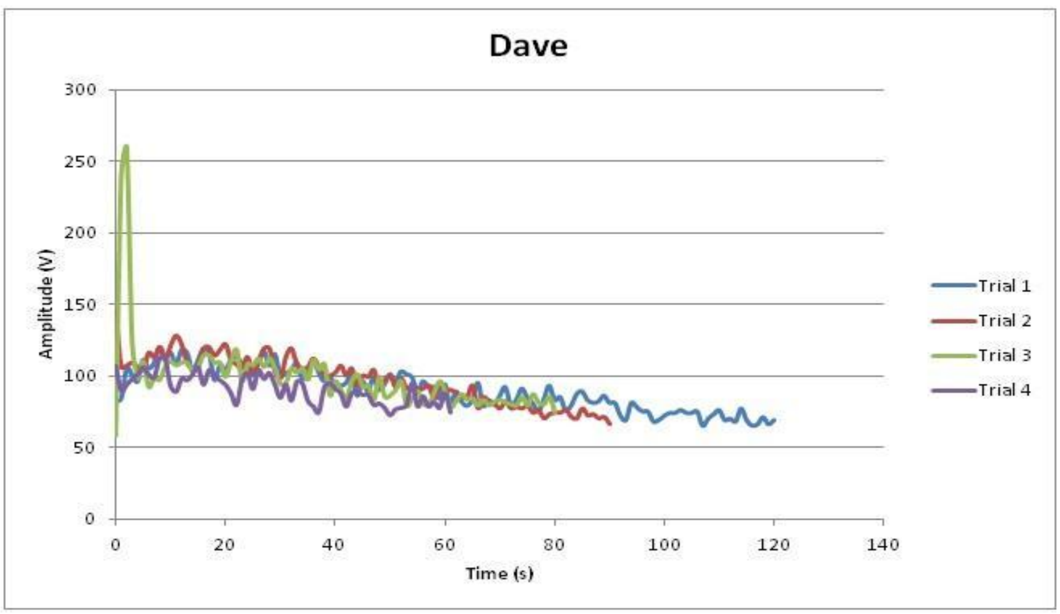

Figure 3.1: EMG Data - Median Frequency of Subject 1

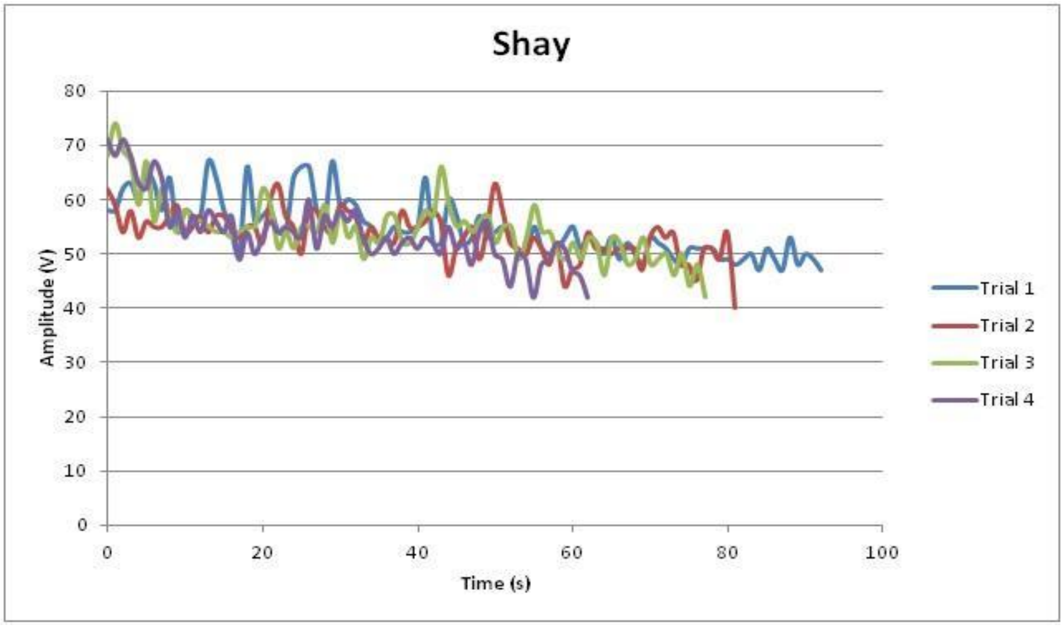

Figure 3.2: EMG Data - Median Frequency of Subject 2

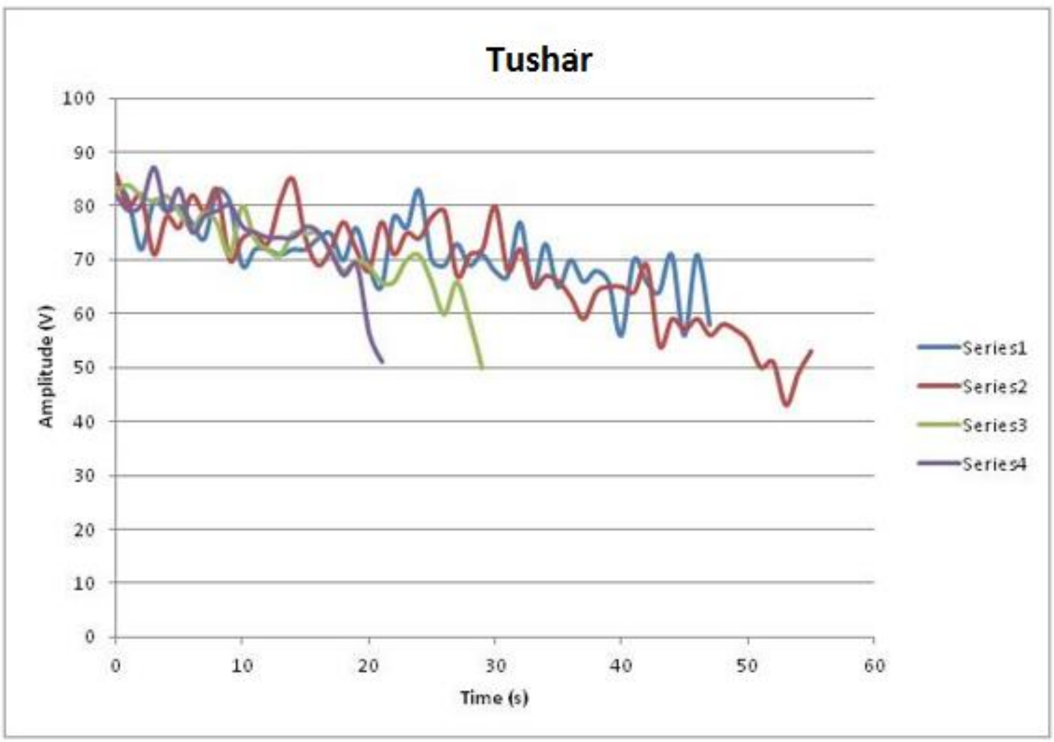

Figure 3.3: EMG Data - Median Frequency of Subject 3

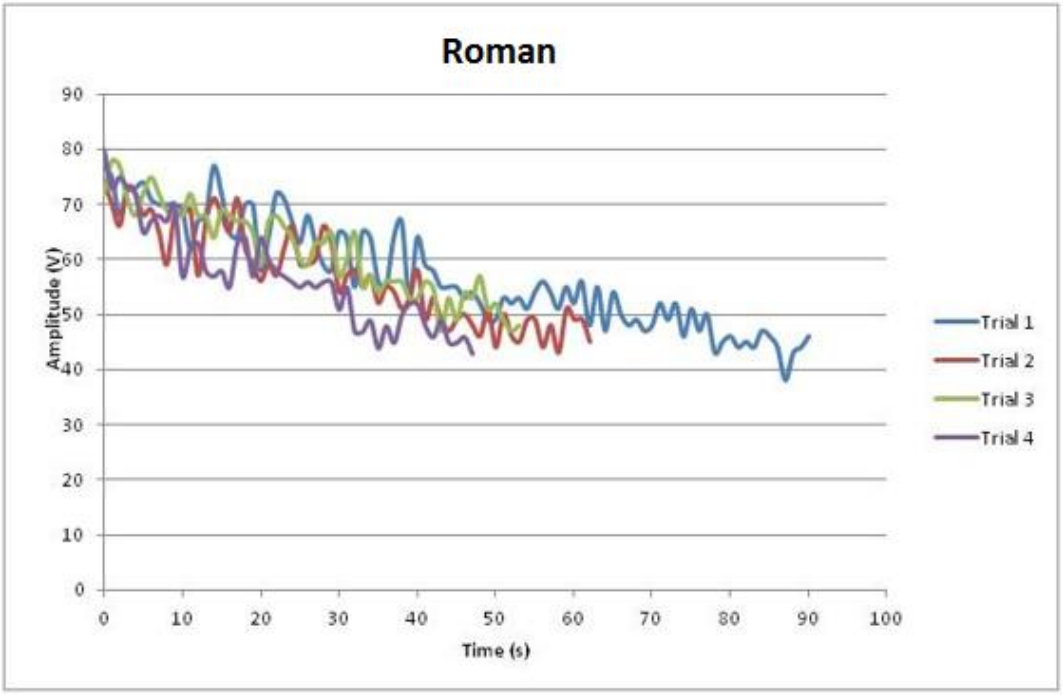

Figure 3.4: EMG Data - Median Frequency of Subject 4

The change of rate of fatigue is a downward trend, as seen in Figure 3.5, for most of the test subjects as expected. As the subject continues to hold a weight, trial after trial, they begin to tire and fail faster. Subject 1 is an outlier to this data most likely due to movement, readjustment after the weight was picked up, and muscle shaking.

Rate of Fatigue (Slope of each trial)						
Test Subject	Trial 1 (V/s)	Trial 2 (V/s)	Trial 3 (V/s)	Trial 4 (V/s)	Avg. (V/s)	Slope over 4 Trials (V/s^2)
Subject 1 – Dave	-0.667	-0.450	-0.613	-0.400	-0.532	.063
Subject 2 – Shay	-0.143	-0.133	-0.179	-0.174	-0.175	-.013
Subject 3 – Tushar	-0.350	-0.429	-0.500	-0.619	-0.475	-.142
Subject 4 – Roman	-0.333	-0.550	-0.800	-1.00	-0.671	-.225

Table 3.1: Rates of Fatigue

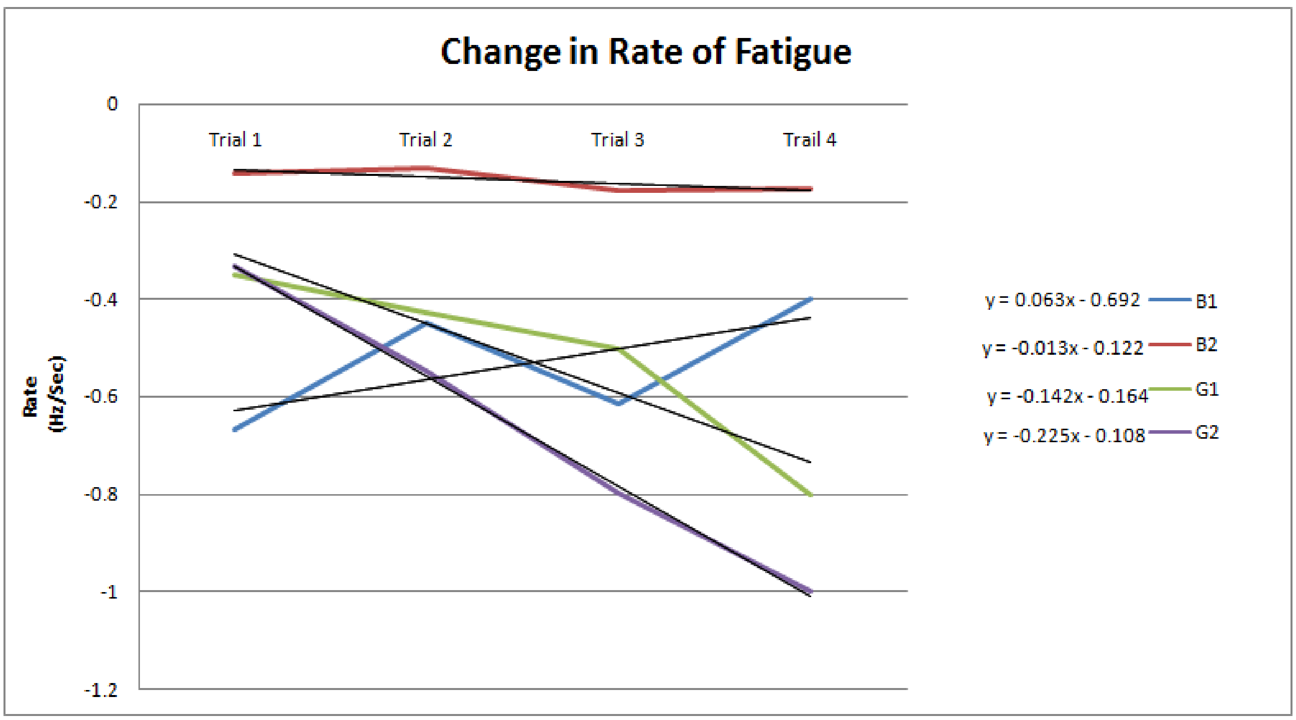

Figure 3.5: Change in Rate of Fatigue

The data may not be as accurate as desired because the subjects had residual fatigue from performing for other groups earlier. Also, it would have been better had it been a blind experiment where the subject could not see the data. Then there would not have been subjects that drop the weight after their data levels off during failure. Our Fail Meter was designed to work on a fixed scale. So if a subject had a higher or lower frequency than normal then our Fail Meter essentially mean nothing to them. Such was the case with Subject 1 - Dave as his median frequency started above 90 while the other subjects started around 75.

The bandpass filter in Labview has a low frequency cutoff at 10 Hz for motion artifacts and a high frequency cutoff for electrode and tissue noise at 500 Hz so it is possible that some of the noise from test subject motion and tissue interference is not completely filtered. This could be adjusted by increasing our low cutoff frequency to approximately 20 Hz and lowering our high cutoff frequency to 480 Hz. However there was another bandpass filter on the bread board in order to ensure that all the interference was filtered out. The EMG system was a third order system: 1 bandpass on the breadboard, 1 bandpass in Labview, and 1 bandstop in Labview. Another source of error could be extra circuit or outside noise that were not filtered out by the bandstop filter with cutoff frequencies of 58 and 62 Hz. So instead frequencies of 55 and 64 Hz could be used, but again the experiment would have to run and check the data.

4. Costs

4.1 Labor

The project averaged 15-25 working hours per week to complete throughout the semester.

Name	Hourly Rate	Total Hours Invested	Total = Hourly Rate x 2.5 x Total Hours Invested
Shay Chen	$25	200	$12,500
Roman Levitas	$25	200	$12,500
Tushar Bhushan	$25	200	$12,500
Total		600	$37,500

Table 4.1 Total Cost for Labor

4.2 Parts

Part	**Cost Per Unit**	**Quantity**	**Total Cost**
Skin Electrodes	$.50	4	$2
Surface Mount PCB	$30	1	$30
Wires	$2.50	2 spools	$5
Resistors & Caps & Diodes	$.10	30	$3
Batteries	$.30	8	$2.40
Battery holder	$3.17	1	$3.17
LED’s	$.15	10	$1.50
Bar Graph Disp.	$4.97	1	$4.97
Metal	$40	1	$40

Enclosure			
Beeper	$5.30	1	$5.30
A/D Converter	$20	1	$20
AD622 op-amp	$2.56	1	$2.56
LM741 op amp	Free Sample	1	-
Arduino UNO R3	$45.65	1	$45.65
78SR-5/2-C DC/DC Converter	$12.36	1	$12.36
Misc.	$20	1	$20
Total			$197.91

Table 4.2 Total Cost for Parts

4.3 Total Cost

Total Cost: $37,500 in labor + $197.91 in parts = $37,697.91

5. Conclusion

5.1 Accomplishments

The designed EMG system is able to take real time samples every second, differentially amplify and filter that signal so it can be used to calculate the mean power frequency. Our data shows that the more times the subject is asked to fail out, the faster the subject will fail out in subsequent trails. The experiment did have its faults such as failure to test the subject blindly and failure to isolate outside motion artifacts. Also the experiment requires more test subjects to conclude beyond reasonable doubt that the change in median frequency would decrease significantly faster as more trials were conducted. However, the experiment provides a solid groundwork for a better experiment in the future, and is functional for further trials.

5.3 Future Work / Alternatives

There is still a considerable amount of work that can be done with the project. Firstly, we would like to be able to make the device portable and thus marketable. This can be done with the help of armbands that have electrodes sown on to them, along with the help of a microcontroller ported onto a PCB, which would give the user feedback as well as process the incoming signal. Additionally, the data logger component can be used to export the data directly onto a SD card outlet mounted on the PCB. This will give the user the ability to have the data immediately and portably.

One of our most problematic areas has been with the microcontroller we had chosen. We used an Arduino R3 with an ATMega 128 processor to perform our calculations. The Arduino has a bit-depth of 8-bits. On the processing side, this translates to the ability for the Arduino to perform 2^8 or 256 instructions per sample. This proved difficult to use to perform DSP functions, because of the limited amount of instruction per cycles the processor is capable of. Our requirements called for the use of a processor capable of performing at least 1024 instructions per cycles. Thus, we would use, instead a dedicated DSP board such as the ADSP-2161 by Analog Devices to perform the needed calculations.

5.3 Uncertainties

There are some uncertainties regarding our finished project. First is obviously how to make it portable with the Arduino. Secondly, our project only works with the bicep muscle. It would be nice to make it useable for other muscles but that would require a tunable gain as different muscles have different EMG amplitudes. Thirdly, we do not know how well this product would perform on the open market.

5.5 Ethical Considerations

Our project aims to provide users with the ability to measure their muscle fatigue while undergoing strenuous activities. While this is aimed towards the gym going user, it also has other uses in the field of medicine, to prevent patients with muscle damage from straining themselves excessively.

The failure of any electrical instrumentation making direct or indirect galvanic contact with the skin can cause a potentially harmful fault current to pass through the skin of the subject. This concern is less relevant in devices that are powered exclusively by low voltage (3-15 V) batteries. To ensure safety, the subject should be electrically isolated from any electrical connection (to the power line or ground) associated with the power source. This isolation is generally achieved in one of two ways: either through the use of optical isolators or through the use of isolation transformers. Both approaches are satisfactory, but both require careful consideration for not distorting the EMG signal. This is especially true when a transformer is used. This isolation provides the added benefit of reducing the amount of radiated power line noise at the electrode detection surfaces.

These functions increase the safety of the user, which is consistent with the first code of the IEEE code of ethics.

1. 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;

One of the factors necessary to avoid muscle fatigue is calculating an accurate baseline frequency for each individual user, and based on these values, the muscle fatigue can be gauged. Throughout the development of this device we will follow the third code closely, and make estimates about the baseline from real data.

3. to be honest and realistic in stating claims or estimates based on available data;

While working on the project, we will build an environment that promote engineer

professionalism, which welcomes constructive and honest criticisms, acknowledges errors, assists
peer workers with their professional and academic developments, and credits appropriate contributions, as cited in the 7th and 10th codes of the IEEE Code of Ethics:
7. to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

10. to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

Additionally, we will ensure that the readings given out by the interface are as accurate as possible and will not provide them with false information, in order to avoid any damage that may occur to a user's health, as per the ninth code of ethics.

9. to avoid injuring others, their property, reputation, or employment by false or malicious

action;

References

[1] Electromyography at the US National Library of Medicine Medical Subject Headings (MeSH)

[2] Moritani, T., & Muro, M. (1987). Motor unit activity and surface electromyogram power spectrum during increasing force of contraction. European Journal of Applied Physiology, 56, 260-265.

[3] Nakra, B. C., and K. K. Chaudhry. "Measurements of Bioelectric Potentials." *Instrumentation Measurement and Analysis*. 3rd ed. New Delhi: Tata McGraw-Hill, 2009. p. 418.

[4] De Luca, Carlos J. "Surface Electromyography: Detection and Recording." Delsys, 2002. http://www.delsys.com/Attachments_pdf/WP_SEMGintro.pdf

[5] Bigland-Ritchie B (1981) EMG/force relations and fatigue of human voluntary contractions. Exerc Sport Sci Rev 9:75-- 117

[6] Dieder. "Fast Fourier Transform (FFT) Tutorial". 05 October 2010. Web. http://www.arduinoos.com/2010/10/fast-fourier-transform-fft/

Appendix A   Requirement and Verification Table

Block	Requirements	Verifications
Electrodes	a. Electrodes can detect a voltage differential. b. Electrodes read voltage values of 50 µV - 50mV on bicep.	a.1 Apply a 10mV PtP sinusoidal voltage from function generator across two electrodes. a.2 Hook output to oscilloscope, Oscilloscope should read 10mV PtP b.1 Wipe skin with alcohol swab. Apply eletrogel to increase coupling. b.2 Connect the electrodes correctly onto bicep skin b.3 Connect the output of the electrodes to an oscilloscope b.4 Measure the values to ensure a voltage range of 50 µV - 50mV.
Instrumentional Amplifier	a. The amplifier needs to have a gain of 30 V/V +/-1.5V/V.	a.1 Check op-amp is powered a.2 Input from the function generator a sine wave of amplitude 10mV. Check the output amplitude for the required gain. Resulting sine amplitude should be 500mV +/-%5 a.3 If the gain is incorrect, use an ohmmeter to test the resistor.
Bandpass Filter:	a. Amplifier passes signals. b. The noise needs to be	a.1 Check op-amp is powered a.2 Use a frequency generator to input white noise. Use the output of the filter to view the Fourier transform on the oscilloscope b.1 Input white noise into the filter (0Hz-1kHz) and view the Fourier transform of the output on oscilloscope

	<2.5μV RMS c. Frequency response needs to be: Low Pass(-3 dB) : 10-20Hz High Pass(-6 dB) : 480-500Hz d. Additional gain of 30V/V e. Bandstop filters out 58Hz-62Hz	b.2 Use oscilloscope to check noise c. Input white noise into the filter (0Hz-1kHz) and view the Fourier transform of the output on oscilloscope d.1 Check op-amp is powered d.2 Input from the function generator a sine wave of amplitude 10mV. Check the output amplitude for the required gain. Resulting sine amplitude should be 300mV +/-%5 d.3 Use ohmmeter to measure resistors. Tolerance +/-5% e1. Input white noise into the filter (0Hz-1kHz) and view the Fourier transform of the output on oscilloscope e2. Frequency response needs to be stopband (-3dB) 58Hz-62Hz
Microcontroller	a. Microcontroller needs to be able to take the signal outputs of the bandpass filter as inputs	a.1 Take the output of the bandpass filter and connect it to the microcontroller. a.2 Make sure DAQ is properly connected and powered. a.2 View the output on LabView to ensure

		correct connection.
	b. It should be able to perform signal processing on the input waveforms	b.1 The output of the processed signal should be free from noise, i.e. there minimal frequencies - less than 6db of >500Hz and <10Hz b.2 This can be verified using LabView to analyze the output signal
	c. Based on these values it should drive the LED display or the sound buzzer as required.	c.1 The output signal of the microcontroller drives power to the LEDs c.2 Once the median frequency is the baseline.
	d. Operating voltage range of 2.4-5.5V	d.1 Connect to power supply to the power supply at 3V, and send a test signal from the function generator and compare with the output signal from the oscilloscope. Voltage tolerance +/-5%
	e. DAQ has a resolution of 10bits	e.1 Feed in a 10mv PtP sine wave e.2 Resulting digital signal should have a resolution of 10bits
LED Display	a. LED Display should interact correctly with user	a.1 Connect LEDs to Vcc and Ground via resistor a.2 Run 2V source from a function generator and see if they light up. Voltage tolerance +/-5%

Sound Buzzer:	a. Buzzer beeps when failure occurs b. Buzzer operates at a voltage range of 2V	a.1 Ensure buzzer is powered a.2 Ensure buzzer is connected to microcontroller a.3 Microcontroller sends signal when failure occurs b.1 Run 2V source from a function generator and see if the buzzer beeps. Voltage tolerance +/-5%
Data logger	a. Implemented via software, run several trials b. Bit error threshold of .1%	a.1 Check if the micro-controller is sending signals to the wireless output. a.2 Check if software is receiving data. a.3 Check software code for errors. b.1 Output a string of 1000 bits. b.2 Resulting data logged on PC should have less than 10 errors.
Power Module	a. Supply a constant 9 volt signal to power the microcontroller b. The supply is stepped down correctly to 5 Volts	a. Use a multi-meter to ensure 9 Volt battery supply and use an oscilloscope to check if the voltage is steady over time. b. A multimeter will be used to check the output of the DC/DC convertor and that the received voltage at the amplifiers is 5 volts ± 0.20V