Instantaneous Tracking of Muscular Activation

Hassler Bueno, Taryn Geivet, Ryan Gottlieb
Nicholas Theriault

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Abstract—For the purposes of instantaneously tracking specific muscle activity, the following electrical circuit was created that gains and filters a traditional EMG signal into a DC signal that can then be used to activate various LED orientations. The LED’s practically convey if the muscles respective to an attached electrode are contracting or at rest. The electrical circuit was simulated on falstad.com and processes the EMG signal as desired resulting in a visual activation when the specific voltage thresholds are met.

Clinical Relevance—The design will allow experts with professions in, but not limited to, personal training, physical therapy, and chiropractic adjustment additional knowledge and understanding on the activities and behaviors of muscles that could potentially be causing pain, discomfort, limited range of motion, injury, neuromuscular disorders, etc. The practical application and usefulness of this design is two-fold because it can also be used to help and protect people with physically demanding occupations that many of our communities are dependent on.

I Introduction

A Improper Musculature Engagement

The combination of ineffective musculature engagement with strenuous physical activities is a widely accepted cause of many injuries. When the musculoskeletal system is required to move strenuous loads it recruits and engages varying musculature to accommodate the task at hand. In some cases not all muscles are recruited properly and the level to which they have been recruited can often end up being poor if existent at all [2]. If certain muscles are not recruited and engaged properly but a strenuous task is still performed it is often done at the expense of over compensation of other muscles in the system due to misaligned movement patterns [3]. This repetitive compensation can eventually lead to overexertion of certain muscles in which case injury is likely to ensue.

In the U.S. Bureau of Labor Statistics it is estimated that the second leading cause of on-the-job injuries are due to overexertion and repetitive stress. Many people who work jobs that lay the foundations of our society are at the highest risk for occupational injury such as: structural iron and steel workers, fallers, reinforcing iron and rebar workers, drywall and ceiling tile installers, roof bolters, miners, firefighters and many more [4]. This design will improve ability to quickly and effectively identify three different levels of musculature engagement: (1) inactive, (2) active, and (3) highly active. By pinpointing muscles that are improperly engaged and allowing for a correction in muscle recruitment and proper training of well balanced and distributed musculoskeletal movement, injury can be prevented.

B Electromyography (EMG)

Electromyography (EMG) measures the electrical activity in response to a nerve’s stimulation of a muscle [1]. These signals are linearly related to the number of muscle contractions. EMG is a fundamental way of tracking muscle activity at various areas in the body based on the positioning of electrodes. The electrical signals can be useful in diagnosing muscle disorders and diseases that affect muscle-nerve connections.

Muscle tissues will not produce electrical signals when at rest, but muscle contractions will. Muscle movements start in the motor cortex in the cerebral cortex of the brain. Action potentials here will carry the signals to each muscle through cells in the brain and spinal cord called motor neurons. Surface EMG electrodes are a non-invasive way to measure this electrical activity. The surface-electrodes are capable of measuring the time and intensity of muscle activation.

II Materials and Methods

A Assumptions

There are two main assumptions being made when creating this electrical circuit and analyzing its performance. The first of these assumptions is the input signal from the electrode ranging from 10μV to 100 mV, which is standard for an EMG signal. This signal varies depending on which muscle is being measured. The second major assumption being made is that the software we are using on falstad.com to create and analyze the circuit is accurate to how the same circuit would behave in real time if it were to be tangibly created.

B Bioinstrumentation Design

The overall circuit design is shown in (figure1) and it consists of 4 phases: signal acquisition, signal processing, signal conditioning and an output display. The goal of the circuit is to acquire EMG biosignals arising from ionic currents during muscle contractions. Then the signal is processed to minimize the signal to noise ratio (SNR) and conditioned to behave DC-like to operate an LED in several modes of operation controlled by the user. The output of the LED will then serve as an instantaneous feedback signal of the inner workings of the muscle activity around the area.
In the signal acquisition stage, a differential amplifier is used to acquire small EMG signals. The differential amplifier measures the potential difference across two points: the region above the muscle of interest and a local bony area. This aids in minimizing the SNR by removing local similarities and amplifying differences across both electrodes. The circuit designed is shown in (figure2) where $R_2/R_1$ dictates the gain of the circuit. In our case, the chosen gain is $1000V/V$ to magnify EMG signals around the $10\mu V$ to $1mV$ region. However, to account for the wide array of biosignal magnitude a further amplification stage is designed and controlled by the user.

The signal processing stage of the circuit consists of an active bandpass filter to improve the SNR and have better control over the magnitude of the signals acquired. The circuit shown in (figure3) depicts a high-pass filter, an amplification stage, and a low-pass filter in series to produce the following transfer function (equation). The signal is filtered around the $10Hz$ and $1000Hz$ region to amplify signals originating from muscle contractions. Ultimately, the cutoff frequencies deviated from our ideal ones due to commercial availability. The high-pass filter stage consists of an $R_f$ and $C_h$, yielding a cutoff frequency of $10Hz$. Similarly, the low-pass filter stage consists of an $R_f$ and $C_l$, yielding a cutoff frequency of $995$ Hz. Additionally, there is an amplification stage that can modulate the gain using the overall circuit by varying the resistance using a potentiometer. The gain can be modulated within the region of $1V/V$ to $100V/V$ dictated by the following equation.

The signal conditioning stage converts the amplified and filtered EMG biosignal to a DC-like by rectifying and low-pass filtering using the circuit shown in (figure 4). The rectification process converts the highly oscillating EMG biosignal to a strictly positive one using a full-wave op-amp rectifier. Further, the low-pass filter is able to acquire the envelope of the signal.
C Modes of Operation

The primary mode of operation involves a set of three parallel LEDs, two of which are connected to comparators whose purpose is modifying the signal to an on and off state for the LEDs. These comparators trigger with logic at different voltages resulting in three outputs (figure5).

![Figure 4: Signal Conditioning Stage](image1)

![Figure 5: LED Display Design](image2)

The LEDs are designed to output (1) inactive, (2) active, and (3) highly active muscle. These three branches run in parallel and the two comparators are connected to branches (2) and (3) respectively. The LEDs provide instant qualitative feedback of muscular activity respective to the connected electrode.

1. Any voltage $V_0$ triggers the red LED.
2. A threshold voltage of $V_{\text{min}}$ triggers a comparator sending current through the green LED, making the output appear yellow.
3. A threshold voltage of $V_{\text{max}}$ triggers a comparator turning off the red LED, making the output appear green.

III Results

A Transfer function

The active bandpass filter has cutoff frequencies at 10Hz and 995Hz with commercially available components. Additionally, the circuit has a 20dB/decade rolloff in the stopband. In regards to the phase plot, signals in the region of interest retain their phase.

$$H(j \omega) = \left( \frac{R_1 + R_2}{R_1} \right) \frac{j \omega R_H C_H}{(j \omega R_H C_H + 1)(j \omega R_L C_L + 1)}$$

![Figure 6: Bode Diagram for Muscle Contraction](image3)

B Signal Conditioning

The signal conditioning stage uses an engineered signal that models the shape of an EMG signal. This signal is then processed by the differential amplifier and active bandpass filter. Since the signal is white noise, the effects of the filter are not as obvious. The rectifier converts the oscillating signal to a strictly positive signal. The addition of the low pass filter converts it to a DC-like signal via an envelope detection.

![Figure 7: Signal Conditioning](image4)


C. Modes of Operation

As designed in the methods section the cases (1), (2), and (3), are displayed below respectively in Figure 8. To clarify an assumption regarding active muscles is being made where $V_{\text{min}}$ is 1/3 of the voltage supply and $V_{\text{max}}$ is 2/3 of the voltage supply. The voltage supply is the maximum voltage from the subject. In a future project this will be better implemented into the main circuit which results in a better estimation for $V_{\text{min}}$ and $V_{\text{max}}$.

![Figure 8: Output Correlation to LED Displays](image)

IV. Discussion

Based on the results of the simulated circuit, the circuit is successful in translating and EMG signal into a physical LED response. This indicates that the LEDs indeed map the level of contraction on its respective muscle. The application of the circuit involves using a multi-electrode array each with the circuit designed attached leading to their own individual LED response. By multiplying the designed circuit by the number of attached electrodes, a spatial map can be created that replicates the spatial orientation of the electrodes on the body providing instantaneous feedback for each individual electrode. This results in the ability to identify inactive, active and highly active muscles at a muscular intersection.

V. Conclusion

The design improves a person’s ability to identify musculature engagement during various types of voluntary and involuntary exercises by providing instantaneous quantitative feedback on muscular endurance, reactivity, and control. This aids professionals in identifying and solving problems relating to musculature engagement imbalances that affects many people in our society today.

References


