MUSCLE ACTIVITY DETECTION OF HUMAN UPPER LIMB USING PIEZOELECTRIC BASED SENSORY SYSTEM

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ABSTRACT

Electromyography (EMG) has widely been used for muscle activity detection and is proven accurate. However, using EMG requires lots of preparation and it is time consuming. Thus, this motivates the exploration of alternative methods. Materials with piezoelectricity effect have gained its popularity not only in the area of structural vibration but have alse emerged as viable sensing elements for capturing biosignals due to its lightweight and flexibility. This research investigates the effectiveness of polyvinylidene fluoride (PVDF) film length in capturing biceps brachii muscle activity during arm flexion and extension. Two films of different lengths were attached to a healthy male subject's arm at specific flexion angles (0°, 90° and 145°) for 30 seconds. The experiment was also repeated with a load of 4 kg and 7kg. It is seen that shorter PVDF film exhibits better performance with an increase of 29.16% peak-to peak voltage at maximum activation . In addition, the higher the load, the higher the voltage generated by the PVDF film. Hence, this study suggests that shorter PVDF is more suitable for muscle activity detection.

Keywords: *muscle activity detection, piezoelectric, smart material, upper limb movement*

1.0 INTRODUCTION

The range of upper limb movements of human body, which includes elevation and depression, protraction and retraction, abduction and adduction of arm as well as flexion and extension of arm are supported and controlled by a lot of muscles and joints on shoulder, arm, neck, elbow and others [1]. These movement of human limb are made possible through the process of contraction, extension, lengthening and shortening of muscles.

The upper arm muscles, which span from the shoulder and the elbow joints, can be grouped into two which are anterior compartment and posterior compartment. The anterior compartment consists of three muscles, which are biceps brachii, coracobrachialis and brachialis muscles while triceps brachii and anconeus muscles constitute the posterior compartment [2].

In the field of biomechanics, the activity of these muscles provide valuable information that can be extracted for many applications in science and technology such as robotic glove [3], [4] , training & rehabilitation devices [5], [6] and prosthetic devices [7], [8]. These detections can be conducted by the means of intramuscular electromyography (EMG) or surface electromyography (sEMG). Nevertheless, though surface electromyography provides a non-invasive alternative to capture electrical signals from the muscle, this method requires skin preparation. In order to overcome this issue, a number of works has focused on the electrodes to minimize or eliminate the needs of skin preparation [9]–[12].

In this work, Polyvinylidenefluoride (PVDF) thin film is utilized to eliminate the needs of skin preparation as well as proposing a low-cost sensory system. Smart materials such as piezoelectric materials, are very potential in converting mechanical energy into electrical energy. Piezoelectric materials are smart materials which have raised increasing interest in recent years due to its ability to respond to changes in their condition or the environment to which they are exposed. Piezoelectric materials are chemically developed in the form of ceramic and polymer. PVDF is one example of polymer-based piezoelectric materials which is able to absorb any strain or stress such as bending, twisting, tapping, slapping and foot striking [13], [14]. Due to its light weight and flexibility, PVDF has an advantage for many applications where flexibility is critical [15], [16].

This paper presents the use of a smart material based sensory system, to capture the activity of the biceps branchii muscle. The overview of the topic is presented is Section 1. On the other hand, Section 2 presents the approach taken to conduct the research, at which the obtained results are presented in Section 3. Section 4 summarizes the work.

2.0 METHODOLOGY

In this work, a normal and healthy male subject was selected. The subject has provided his written and informed consent by signing the consent form prior to the experiment. Approval for the experimental procedure was obtained from the IIUM Research Ethics Committee (IREC).

2.1 Smart material based sensory system.

To capture data from the muscles, Polyvinylidenefluoride (PVDF) material is utilized in the experiment. This material was chosen as it is flexible, durable, can be obtained at a low cost and does not require high maintenance. To record the signal, National Instrument (NI) USB-6008 was used. The output of the sensor was then fed through a low pass filter with amplifier circuit (gain = 11), before being acquired by the DAQ. The sampling rate of this experiment was set to 1000 Hz, which means every 1 seconds, 1000 data was collected and recorded for analysis. The smart material based sensory system is shown as in Figure 1.

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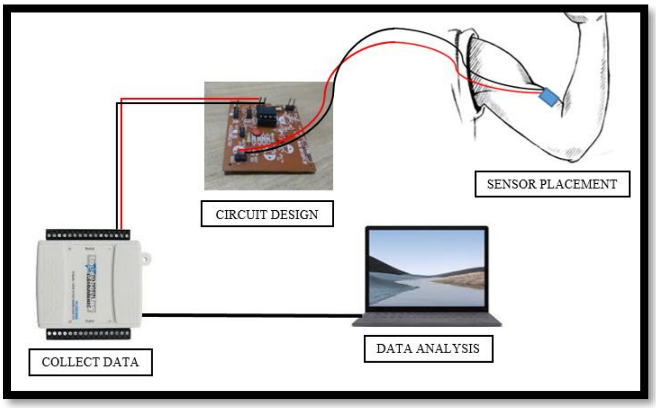

Figure 1: Experiment setup to detect muscle activity using PVDF thin film sensor

2.2 Sensor placement

In this work, two TE Connectivity's PVDF films of different lengths were used to study the effect of length on the generated voltage, as shown in Figure 2. The total thickness of the two films remains the same at 40µm.

(a) (b)

Figure 2: PVDF thin films used in the experiment.
(a) 16 mm x 41 mm x 40µm and (b) 16 mm x 73 mm x 40µm

The placement of the PVDF sensors was first identified. It is recommended that the PVDF thin film sensor is placed on the muscle belly of the biceps brachii muscles of the dominant hand of the subjects [17], [18] . The dominant hand was chosen in order to minimize interference by signals from the heartbeat and electrocardiogram (ECG) [17]. The sensor was placed on the line between the medial acromion and the fossa cubit at 1/3 from the fossa cubit as suggested in SENIAM [19]. To attach the sensor on the skin, a double-sided adhesive tape and an armband was used, as shown in Figure 3.

Figure 3: Placement of sensor attached using double-sided tape and armband

2.3 Circuit Design

A low pass filter was designed in this experiment to remove the high frequency noise generated from the PVDF thin film. The cut off frequency was set to 120 Hz. For amplifier circuit, the gain was set to 11. The amplifier was calibrated and scaled to improve the respond of the weak vibration of the PVDF thin film [20]. The circuit was first constructed and simulated using an open-source software, Multisim, as shown in Figure 4. Both numerical calculation and simulation work yield the same value of voltage output amplified by the circuit.

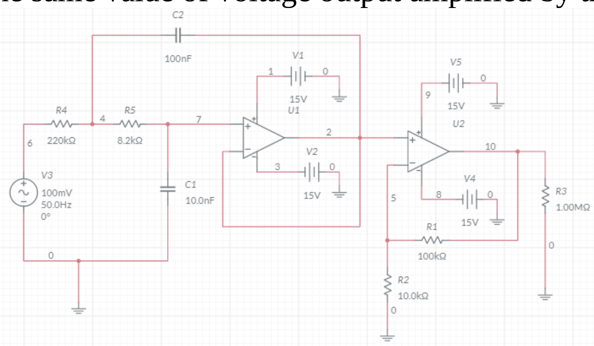

Figure 4: Low pass filter with amplifier circuit

The schematic shows a two op-amp, dual DC power supply (+l5V / -15V) design. The first op-amp serves as a low pass filter while the second op-amp serves as non-inverting amplifier in the circuit. The output range of the circuit is -15V to 15V due to the DC power supply supplied to the op-amp. The AC source, V3 illustrated the PVDF thin film sensor during the simulation with 100 mV peak-to-peak voltage at the frequency 50 Hz. Upon validation using simulation, the circuit was then fabricated on a PCB to be used during the experiment. The fabricated circuit, as seen in Figure 5, was then tested using Function Generator to ensure the filter and amplifier circuit is functioning well.

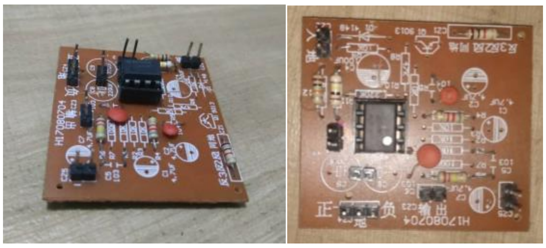

Figure 5: Fabricated circuit of low pass filter second order with non-inverting amplifier

2.4 Experiment Procedure

In this work, the detection of muscle activity using PVDF thin film sensor was done for flexion and extension movement. As mentioned before, two sizes of PVDF films were used to study the effect of size on the voltage generated. To collect the data, the subject was asked to stand in an upright posture. This is considered as the initial position. The subject was then required to lift his hand freely without load for 0°, 90°, 145°, 90° and 0° where 145° is the maximum angle of flexion of hand. For angle 0° and 90°, the signal was recorded in 5 seconds for each while 10 seconds for 145°, as shown in Figure 6. The first half of the interval refers to the flexion of arm, while the second part constitutes the arm extension. During the experiment, the subject should not move his shoulders but only lift the load by using his hand in flexion and extension movement, as depicted in Figure 7 until Figure 9.

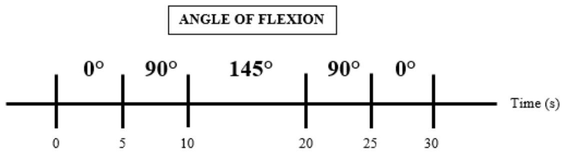

Figure 6: Experiment procedure in 30 seconds

Figure 7: Position of body when flexion angle is 0°

Figure 8: Position of body when flexion angle is 90°

Figure 9: Position of body when flexion angle is 145°

The repeatability for each experiment is 3 times. The data were recorded continuously for each take before it was stopped for another set of data taken. The repeatability of these data was used to improve the accuracy of the data by calculating the average voltage generated by the PVDF thin film which indicates the detection of the biceps brachii muscle activity.

The whole experiment was repeated with a dumbbell load of 4 kg and 7 kg. 7 kg of load is considered the maximum load that a normal and healthy person, male or female, can lift using a dumbbell with a single hand. For each load, the subjects had 5 minutes of rest when changing from one weight of load to another in order to avoid muscle fatigue.

3.0 RESULTS

In this section, the data collected from the short PVDF film at no load is set as the reference. Hence, the highest nominal value, which is at 1, refers to the highest voltage produced by the film at no load. In general, from Figure 10, it is seen that the performance of shorter PVDF film is better, demonstrating a remarkable 29.16% increase in peak-to-peak voltage at maximum activation. . This observation matches with the simulation study conducted using COMSOL Multiphysics software, prior to this work (Figure 11).

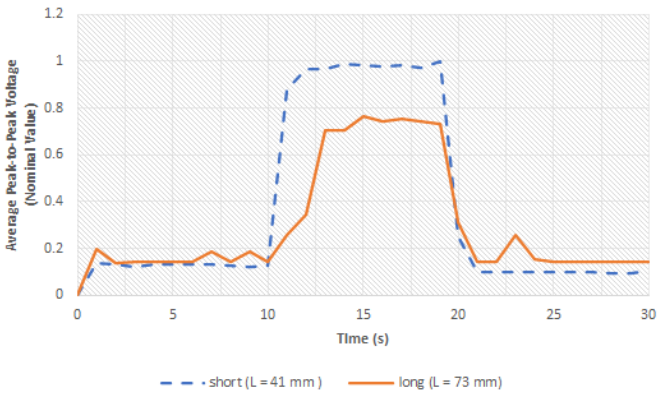

Figure 10: The nominal value of the average V_{pp} generated by different sizes of sensor

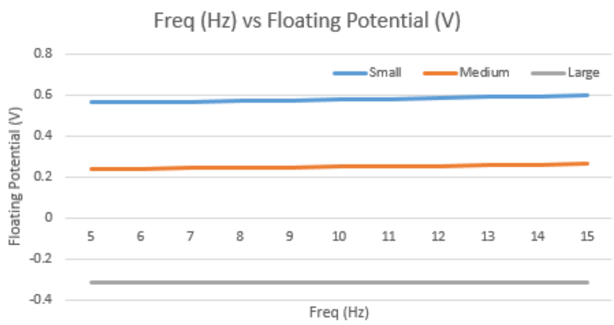

Figure 11: Simulated voltage produced by three different sizes of PVDF films, obtained using COMSOL Multiphysics software (small = 10 mm x 10 mm x 0.03 mm, medium = 15 mm x 15 mm x 0.03 mm, large = 20mm x 20 mm x 0.03 mm)

At 10s < t < 20s, when the angle of flexion is 145°, a large different of amplitude between the two films is observed. However, other regions show no significant difference between the two sizes of PVDF films. This shows that the thickness of the total PVDF films used in this experiment is more suitable at detecting muscle activities at a larger flexion angle only. Hence, it can be deduced that PVDF films with lower total thickness should be used for future works so that all data across the muscles' activity can be successfully captured.

The experiment was then proceeded with varying loads. Two dumbbells, that weigh 4kg and 7 kg, respectively, were used to study the amount of voltage generated during hand lifting. The short PVDF (length = 41mm) was used as it is proven this PVDF film is able to produce more voltage. The relationship between changing in force during muscle contraction and increasing of load can be observed in Figure 12. It is observed that as the weight of the dumbbell increases, the voltage produced by the PVDF film increases as well. Higher voltage indicates more muscle activity during this interval. However, due to the limitation of the sensors used, only data captured at the angle of 145° can be clearly seen.

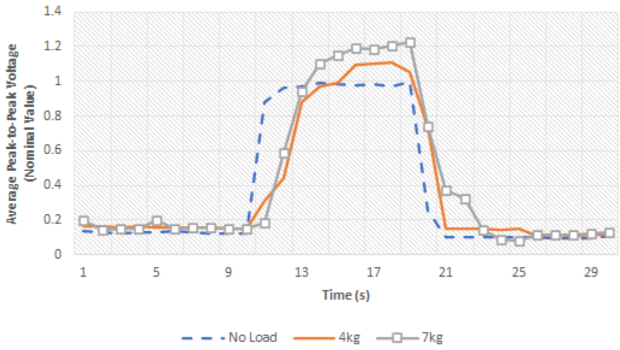

Figure 12: Average Vpp generated for different load

4.0 CONCLUSION

This paper studies the responses of two different sizes of Polyvinylidenefluoride (PVDF) film in detecting muscle activity through arm flexion and extension. To do so, the smart material based sensory system was first set up, in order to successfully capture the data from the muscle to be processed. In terms of the length of the sensor, the work concluded that short PVDF can generate higher voltage as compared to long PVDF, which is in line with the simulation studies done at an earlier stage. A series of experiments with different loads were carried out, where it shows that the PVDF film is capable of detecting the activity of biceps brachii muscle. In addition, it is also observed that the total thickness of the PVDF film should be as small as possible in order to successfully acquire the required data from the muscles.

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