Development of wearable electromyogram (EMG) device for upper extremity in aerobic exercise

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Development of wearable electromyogram (EMG) device for upper extremity in aerobic exercise

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Abstract. The demand on the wearable device in sport for health monitoring is increasing due to the awareness among the people while they undergo any physical activities. Therefore, the purpose of this study is to develop a wearable surface electromyogram device that can be used to measure and to monitor muscle activity during aerobic exercise. A 10-bit analog to digital converter (ADC) micro-controller board is selected to obtain and process the data sensed by Ag/AgCl wet electrodes. The obtained data is transmitted to the computer via Bluetooth's wireless technology using HC-05 master-slave module. In prior, the wearable is attached to the palmaris longus muscle in two different activities known as isometric and isotonic contractions. The fourth-order Butterworth filter is applied to eliminate the noise and filtering the raw signal in order to produce a clean EMG signal. Then, the device is compared with the commercial EMG to validate the signal obtained and to ensure the result is reliable. The results reveal that the high consistency of the voltage amplitude is successfully achieved in the high reliability of exercise voluntary contractions especially for isotonic and isometric. These types of contraction are distinguished able from the pattern of signal. The error of signal analysis is < 5% in validity test verified the accuracy of this device compared with the other device available in the market. This device is potentially can be used for upper extremity of aerobic exercise in measuring the muscle contraction, and it is beneficial for the biomedical and sports application environment.

1. Introduction

Health has become one of the highly concerned and cared by people around the world. It can be observed from the increment demand on the health-monitoring device in the market. Consequently, many medical device companies trying to place their products and compete between each other to provide a better wearable device to their potential customers. On top of it, a healthy and safe activity in the context of an aerobic exercise requires information on the muscle mechanism in its muscular system obtained from the wearable health-monitoring device. It is due to the body movement is imitated by the contraction and relaxation of the muscles during exercise.

The common use device that measures the muscle contraction during exercise is identified by using the electromyogram (EMG). It can be invasive with the used of needle or non-invasive technique via surface electrodes respectively. Nevertheless, the most popular method is non-invasive with wet surface electrodes Ag/AgCl applied onto the skin on selected muscle. Therefore, there are plenty of researches conducted used EMG to measure the muscle fiber activities during contraction and relaxation [1]–[5].

Moreover, the size of the equipment is bulky and is not suitable for the outdoor setting that requires movement experiments.

On the other hand, different manufacturers provide a different algorithm of signal processing (i.e. results) interpretation. This is due to different experiment settings conducted to meet the standard and specifications by the authority or government. In fact, the validity and reliability tests also need to be conducted for all new prototype that has been developed and ready to be clinically tested. However, the requirement for each experiment is different, and custom depends on the experiment protocol set by the authorities. Therefore, the development of health wearable device is a must and becoming important to meet the market demand in order to accommodate the people needs.

1.1.EMG development
The EMG measurement used differential amplification of potential voltage in both positive and negative electrodes at two different sites of the muscle. An electronic circuitry subtracts the two signals and then amplifies the difference (m_1-m_2) as shown in Eq. 1. Nevertheless, noise (n) which disrupted its originate EMG signal is coming either from the internal source (i.e. the electronic) which amplifies the signals or the external sources (i.e. the powerline) or from the experiment setting itself. This drawback can be removed by applying the subtract method when the amplified signal is merely showed difference values.

$$(m_1 + n) - (m_2 + n) = m_1 - m_2 \quad (1)$$

Digital or analog amplifier is required to amplify the difference between signals also to display the strength of signal in voltage amplitude.

1.2. Muscle contraction
There are three general type of muscle control contractions in exercise which is; 1) isometric contraction (same position), 2) isotonic contraction (same force) and 3) isokinetic contraction (same velocity) [6]. For upper limb exercise, few studies conducted several experiments including in grasping the hand dynamometer [3], [7], hand position [8] and lifting the dumbbell [4]. Conversely, for the lower limb exercises were focus on the cycling [9], walking [10] and running [11]. Every muscle contraction will amplify the EMG signal to the maximum amplitude according to the number and size of muscle fiber activation. Muscle contraction also shortens its length and form a concentric as sliding between actin and myosin in the muscle fibers structure.

1.3. Signal processing for EMG
There are several types of signal processing that are commonly used in extracting the useful signal by using the analysis such as wavelet transform, Fast-Fourier transform [12], auto-regressive model [13], and combined method [14]. However, Al-Mulla [15] suggested a short-time Fourier Transform (STFT) as the feature characteristics selection instead of fast Fourier Transform (FFT) since the physiological signals such as EMG is a non-stationary technique. Therefore, results should be presented in both the time and frequency domains in a small temporal section of the signal.

To date, the use of EMG in measuring the muscle activity during exercise is becoming the common practice in research. This technique is not practically used if the size and data transmission are bulky and wired. Therefore, the objective of this study is to develop a custom wearable device for surface EMG in biomedical measurements during aerobic exercise. This device is fully guided and monitored by the user to monitor the EMG easily by using wireless technology and undisrupted the movement.

2. Methodology
ATMEGA328 micro-controller was used to provide 10-bit resolution by analog to digital converter (ADC) including 6 channel of A/D converter with 16kHz sampling speed. There are 2 such preamplifier IC sections for EMG extraction, arranged in cascade mode, which is INA126 and OPA347 (Figure 1). Each IC was powered by 3.3V, supplied by VCC from micro-controller. INA126 works as the

differential amplifier to digitally subtract the signal in between pin 2 and pin 3, then the output of signal at pin 6 were consequently amplified at OPA347. It is complying to the subtract method that presented earlier. Pin 2 and 3 were used the audio jack to be separated two bipolar electrodes in between positive and negative conductors while another electrode as reference is for ground.

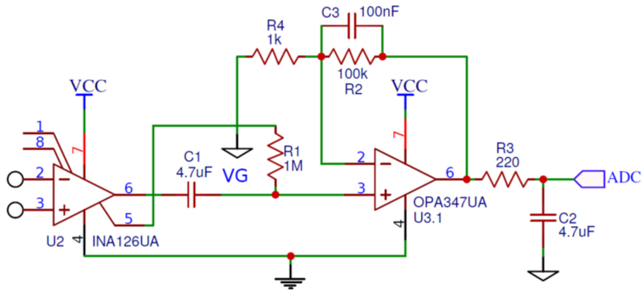

Figure 1. Schematic circuit for EMG device

For the wireless transmission, Bluetooth module HC-05 with 2.4GHz frequency was used to transmit the data to computer. It works in the range of 5m connection using ISM band and provides the reliable and high-speed data transmission. Also, the low current draws only about 20mAmp and runs in 3.3V supply which further aids the system in low power design. A simple code was programmed in the micro-controller to automatically offset the raw signal into 0 value by differentiate with the reference value in that pin. This process was done in the ADC with 184Hz sampling rate frequency.

The wet biopotential electrodes Ag/AgCl was attached on the skin surface exactly at the belly of the selected muscle (palmaris longus) on the forearm and interelectrode distance 3.8 cm[17]. This is to ensure that the maximum activity of the muscle fibres was measured at that point. A simple exercise which can activated the palmaris longus muscle is by using the hand gripper device with apply an isotonic and isometric contractions. Inter-electrode distance was placed about 5cm as minimum as possible for reducing the noise generated from the skin friction and movement.

The overall processes to analyse and validate the signal is shown on the Figure 2. The electrode location needs to be prepared properly by removed all the hair and clean up the skin with alcohol. Then, the device connected and pair with the computer Bluetooth for the data transmission. This process will take some time to find the correct address for the first-time connection. Repetition is required if the signal lost or unsuccessful.

Raw signal from the device were transmitted to the computer for the post-processing analysis by using the Matlab software. Then, it was filtered by a band-pass frequency to remove motion artefacts within bandwidth 10 – 500Hz [9]. Prior to that, power line noise for 50Hz was removed to separate the interference with EMG signal. The strength of EMG signal is referred to the power of millivolt whether in positive and negative values. Therefore, to ensure all the signals in a positive side, it needs to sum up by using the method of “full wave rectification” through the absolute function. As a result, it looks like the “envelope” of the original signal.

The 4th order of Butterworth filter as one of the type of infinite impulse response (IIR) filter is commonly used by researchers to smooth the signal [1], [16]. It is often applied in both directional way in forward and backward because this results in zero phase shift [16]. Prior to that, Fast Fourier Transform (FFT) was performed to identify the value of cut-off for low-pass frequency. The low-pass frequency in Butterworth filter is traditionally helping to extract only the right signal for analysis due to the blend up of signal in the raw data.

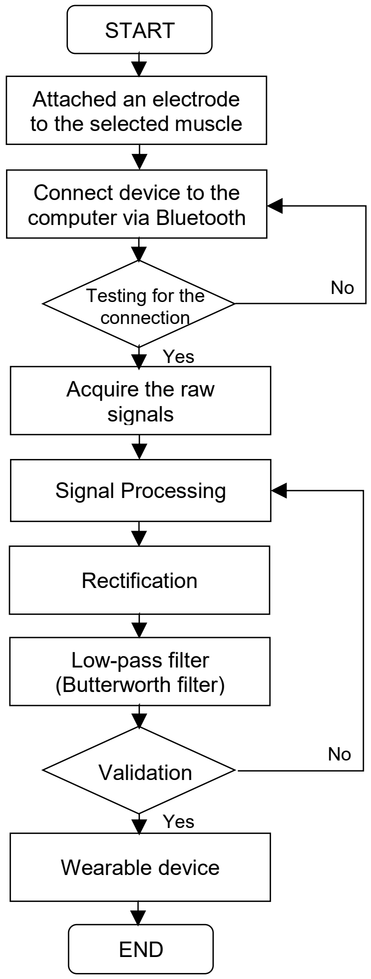

Figure 2. Process flow of the EMG device testing.

For the validation of the measurement, the results of the wearable device were compared and experiment was repeated with the commercial EMG device (Attys, GlasgowNeuro, UK) equipped with Bluetooth and sampling rate 250Hz. The electrodes were attached nearly for both measurements on the same muscle selection. When the activity was performed, both devices recorded simultaneously in real-time monitoring. The manipulative parameters are the type of exercise, amplitude and time of contractions.

3. Results & Discussion

A printed circuit board (PCB) was developed by manually etching in ferric chloride. A prototype of the EMG device indicates in the Figure 3, consists of two IC which is OPA347 and INA126 as its pre-amplifier mechanism. An audio jack was connected to the wet electrode by combining three of those electrodes which is positive electrode (+), negative electrode (-) and ground as reference. For connectivity, Bluetooth HC-05 was integrated into this PCB with 57600 baud rate, similar with serial receiver setting in computer. Microcontroller 10-bit ADC was attached by stacked up via pin header slot on this PCB shield and powered with 3.3VLipo battery. Finally, several electronic parts such as resistor and capacitor were applied for completing the circuit

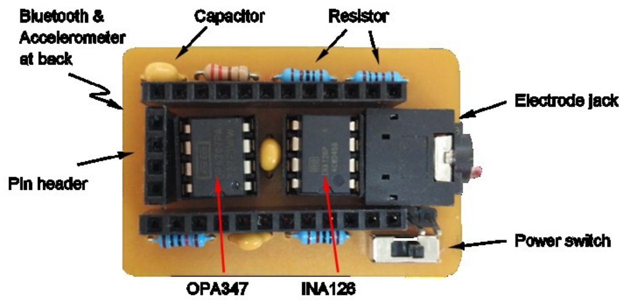

Figure 3. Soldered PCB board for EMG device

The advantages of this prototype are the device capability to have 2-way communications in measuring EMG signal wirelessly and upload the code by using computer or smartphone. Furthermore, the size is comparatively small which mobile and also can be attached to the body as wearable device. The most important thing is the signal processing method in delivering the results can be easily troubleshooting as it designed to meet their own specification and requirements. Consequently, this device is prototype and suitable only for the research purpose and require minimal maintenance.

Raw signal in Figure 4 which generated from the serial port, indicates the isometric contraction of the forearm specifically at palmaris longus muscle. The consistency of muscle activation is due to constant force applied on the hand wrist gripper. The pattern of the signal almost similar with the previous study that conducted on the same activity via commercial EMG [3]. At this point, the signal was eliminated the powerline noise 50Hz from the environment.

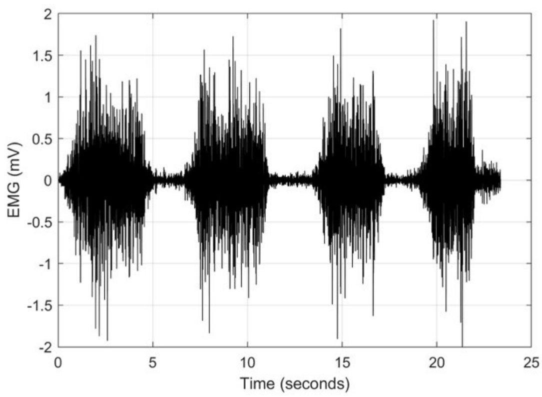

Figure 4. Raw data from the device

In order to rectify the signal, a full-wave rectification by absolute all the values into positive swing side will elucidate the real muscle activation and swift the signal to the zero position of amplitude (Figure 5). This process also could segregate the real EMG signal and the noise.

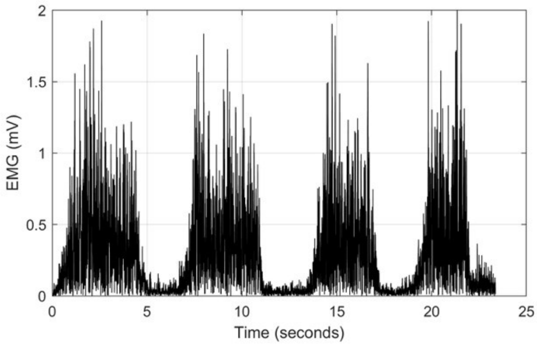

Figure 5. Full-wave rectification

The final stage of filtering signal is smoothing, when the raw data enveloping its raw data as illustrates in the Figure 6. The previous rectification signal was enveloped by the single line to cover the whole measurements. The maximum and minimum amplitudes of the isometric contractions to grip the hand wrist gripper are 0.617mV and 0.3859mV respectively. Overall attempt presents the voluntary isometric contraction by 0.4805±0.0624mV. A consistency value for each attempt reveals that the high reliability of this device when performing the same activity repeatedly. The amplitude value of each voluntary contraction is different for each user because the biological uncertainty. It depends on the muscle fibres activation which refer to biological, lifestyle, exercise and etc.

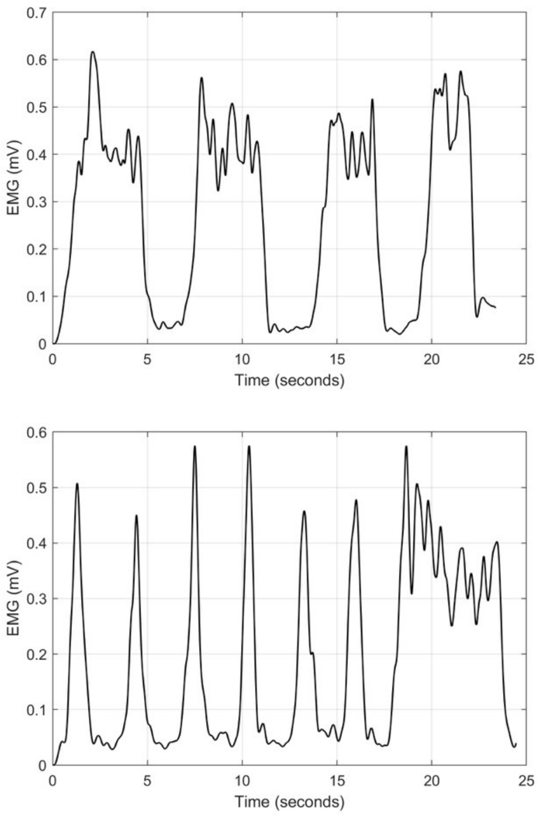

Figure 6. Butterworth filter for isometric and isotonic contractions

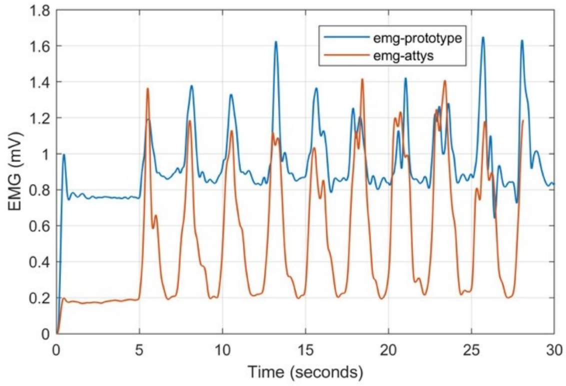

Figure 7. Comparison of the signal for the isotonic contraction

However, Figure 7 indicates the different exercise that can be easily distinguished on its pattern and time of contraction. At the first sixth attempts, the hand was grasping the gripper by using isotonic contraction method while the last attempt was hold for isometric contraction. Isotonic was observed as one signal with high spike while isometric produced the fluctuation signal for a longer time. This is due to the muscle twitch response is quicker for isotonic rather than isometric. Even though the grasping was repeating for both isotonic and isometric contractions, the amplitude of voluntary contraction still produced almost the same value which is 0.4679±0.075mV.

As validation, the signal of the prototype device was compared with the commercial device Attys EMG. The comparison of both devices for isotonic and isometric activities are shown in the Figure 7 and Figure 8 respectively. The EMG prototype was presented in blue and orange for Attys. However, the amplitude value for the current EMG was amplified higher to contrast the signals and compared with the pattern of contraction.

It is illustrated in the graph with different length due to the dissimilar sampling rate of measurement which is 184Hz vs 250Hz. Therefore, EMG Attys is shorter than the prototype because it was shifted to the left to ensure the same starting point of contraction. Surprisingly, the time of contraction for both devices almost similar which is less than 5% of errors in isotonic and isometric activities. In tenth of contraction attempts (Figure 7), all of them contributed the similar pattern with the right time of contraction induced. In contrast, the peak of contractions showed the distinguished value in each data. This might be the location of the surface electrodes were not on the exactly at the muscle fibre during the experiment. The distance between both pair electrodes are noticeable bigger since the size of electrodes slightly greater.

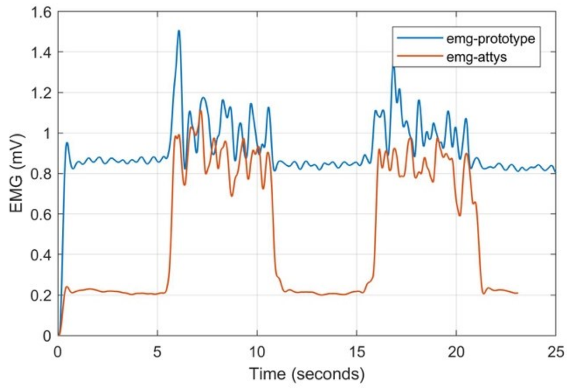

Figure 8. The evaluation of the isometric contraction for both devices**.**

In addition, the slight differences of amplitude and pattern for each device provide the changes electrical activity in response to a nerve stimulation of the muscle. Again, this is due to the electrode was placed on the different location of the muscle fibre even it was near each other and it also interfered the signal for both devices. The skin and the pair electrodes produce impedance which well-managed by the Attys EMG in the hardware design circuit but not for the current prototype. The signal appeared in this result is totally from the raw data that filtered using the same procedures for both devices. Therefore, current practice and process should be reviewed and adjusted accordingly in the prototype, thus to ensure the results and data obtained completely similar.

4. Conclusion

The objective of this study is to develop a functionable of EMG device to be used in aerobic exercise is accomplished. Even though it has some drawback and flaws, but the measurement still in the accepted range 5% of error. An experiment was conducted in this study, produced promising results to identifying the type of contraction at palmaris longus muscle. The trend of EMG signal is well agreement with the previous researches. A consistency of results indicates the high reliability of EMG measurement during exercise. This system could be useful in monitoring the muscle activity for sports and rehabilitation environments. Future recommendation is to include more channels to ensure that the measurement will be monitor for two muscles simultaneously. Moreover, the monitoring will be interactive and simplified if the data transmission were directly sent to the smartphone for the record and analysis purpose.

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