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LOW COST AND WEARABLE MULTICHANNEL SURFACE ELECTROMYOGRAPHY DATA ACQUISITION SYSTEM ARCHITECTURE

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Abstract

Electromyography signals is one of the most important studies of muscle function used in wide area including kinesiology, rehabilitation, and occupational and sports medicine. The measurement of electromyogram always requires multichannel as every movement will involve a group of muscles. Commercial single or multichannel surface electromyogram data acquisition system is very expensive for beginner researcher. Some of the systems are available in bulky device, heavy and not portable. As electromyogram detected once muscle is active and contract, a wearable device is desired since several movement will involve during measurement is taken. Therefore, this paper presents architecture of low cost and wearable multichannel surface electromyogram data acquisition system. It is light weight, low power consumption and using stacking system as numbers of electromyography channels used can be varied based on application.

Keywords: Surface electromyography, Multichannel EMG, Data acquisition system.

1. Introduction

Each activity of organ in human body will represent by a signal called bio potential. It includes muscle fibres where electric activity will generate every times muscles are active [1]. Any concerned to muscle activity which involve development, measurement and analysis of myoelectric signals is refer to electromyography (EMG) [2]. The amplitude of EMG signal can range from 1 to 10 mV within 20 to 2000 Hz frequency bandwidth, where the dominant energy is in the 50-150 Hz frequency range [1-3]. EMG can be detected through invasive and non-invasive method depends on the type of electrode used and application.

Abbreviations	
EMG	Electromyography
FFC	Flexible Flat Cable
IA	Instruments Amplifier
ISM	Industrial, Scientific and Medical Band
UART	Universal Asynchronous Receiver/Transmitter

Although invasive method will always give accurate measurement and detection, non-invasive method also offers many advantages since it easy to apply and prepare, less pain and suitable for recording which need patient to make any movement [4]. EMG not only used in clinical and diagnostic, but it also established as an evaluation tool in kinesiology such as ergonomics analysis, rehabilitation and physiotherapy, sports training and human-robot interface or prosthesis [2, 5-6].

To date, there are several manufacturers develop commercial EMG device system for research and monitoring purpose like BIOPAC, NORAXON and DELSYS. The systems not only acquire EMG signals, but it equipped several added system such as data logger, wireless and multichannel recording. The system can be available in a bulky machine or handheld/ portable as it can suit to application accordingly. However, the price can reach thousand dollars to hundred thousand dollars for each EMG system. The expensive price of EMG system will limit research works especially for beginner researcher which requires large number of EMG channel with limited budget.

Cheney et al. [7] mentioned about price comparison between commercial products and their own low-cost, multi-channel, EMG signal amplifier. This paper proposes cost effective solution for experiments and researches which require large numbers of EMG channels. Their own EMG module which consists of five stages signal processing and buffering only cost $75/channel compared to $1000/channel from commercial products.

Al-Imari et al. [4] present surface electromyogram system for sport field application. They also considered low cost and simplicity during determine the system design. An operational amplifier 741 is chosen to design instrument amplifier with specification 100dB of CMRR at 50 Hz, gain G = 1000, input impedance > 10 MΩ and output impedance < 10Ω. Several filter stages also added such as notch filter and low pass filter. However, only one channel EMG access was offered.

Kundu et al. [6] designed a wearable, low power, single supply surface EMG extractor unit for wireless monitoring. Dual polarity supply in AD620 force them to use AD623 which only demand single supply, but offers same gain range, 2 GΩ input impedance, and low noise operation. Band pass filter cut-off at 10 Hz and 500 Hz added before ATMEGA8 processor for 10-bit analog to digital conversion and data is sent via wireless by Zigbee. Two channels of EMG is offered and further EMG analysis done in PC.

The objective of this paper is to develop a low cost and wearable multichannel EMG acquisition system which suitable for beginner researcher of EMG field area.

Proposed design will involve more than two channel EMG recording, small in size as it wearable, low power consumption, wireless design, and affordable to build.

2. Design Considerations

The system will divided into two main blocks, which are data acquisition and data logger as in Fig. 1. This paper will focus on data acquisition since it will be designed as in objectives mentioned before. A non-invasive method of measurement using *Ag/Ag Cl* electrodes is chosen. As shown in Fig. 1, data acquisition system will involve three main stages; pre-amplifier, microcontroller and wireless module. Surface mount components are used in this system as it can designed it small and suit for wearable device. The decision to use wireless is important since in kinesiology, movement is needed during EMG measurement.

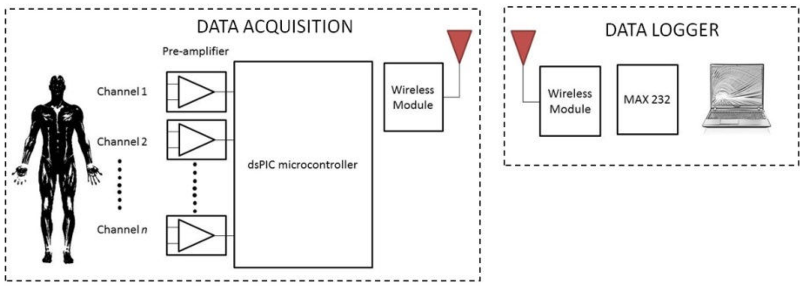


Fig. 1. Block Diagram of the EMG System.

Each channel of EMG signal will be picking up from pre-amplifier unit. Every pre-amplifier unit will be consists of instrumentation amplifier and notch filter. Numbers of channel can be used depends on users and numbers of input can be read from microcontroller. There are many considerations during choosing each component especially microcontroller since biopotential signals involve negative signals. Although level shifter can be used to solve negative signals reading, dsPIC family types of microcontroller offers simple signal processing embedded inside it other than solve negative signals reading. Reducing several parts like level shifter and filter stage will lead to reduce component used. It is not just cost effective, but it also saves space.

All measured data will be transmitted via wireless module then saved in PC for further analysis as the behaviour of detected muscle is difficult to determine based on amplitude and time domain only.

2.1. Pre-amplifier circuit

The main design of the EMG system will be based on basic circuit of biopotential amplifier. Instruments amplifier (IA) is the key component on designing biopotential circuit. From three discrete amplifiers which form differential amplifier, it has been combined and called as IA. AD620 is one of the IA from Analog Device which offers better performance in term of accuracy, drift and resolution compare to three OP07 in differential amplifier [8]. It also offers high

CMRR, 130 db (G = 100) and low power consumption, 1.3 mA. AD620 also offers low input voltage noise of 9 nV/√Hz at 1 kHz, 0.28μV p-p in the 0.1Hz to 10 Hz band, 0.1 pA/√Hz input current noises make in suitable for preamplifier [8]. This low cost and high accuracy IA only requires only one external resistor to set gains up to 1000 based on Eq. (1)

$$G = \frac{49.4k\Omega}{R} + 1 \tag{1}$$

The system gain is 248 where the resistor that is connected between pin 1 and pin 8 is set to 200 Ω. *Ag/Ag Cl* electrodes will be connected to pin 2 and pin 3 of AD620 IA as shown in Fig. 2. In order to increase CMRR, reference electrode will be connected at GND of the circuit.

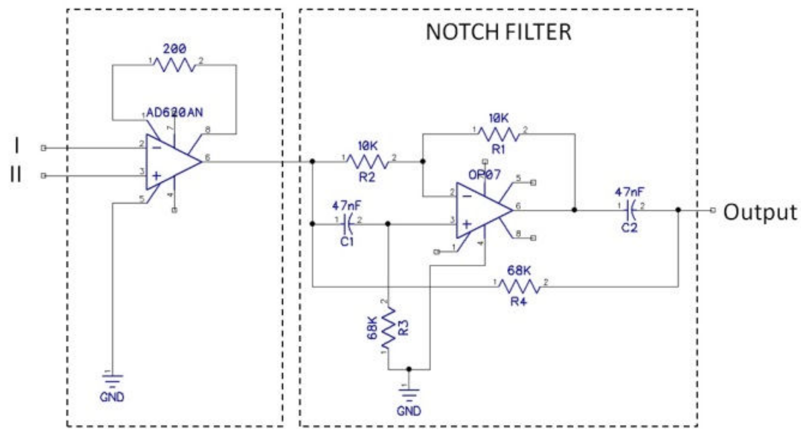


Fig. 2. Circuit Design of EMG Channel.

Recording of biopotentials are often done in an environment that is equipped with many electrical systems that produce strong electrical and magnetic fields. 50/60 Hz power line may affect the biopotential measurement due to strong harmonics created. The interference can be minimized by increasing the distance between power lines and body, use isolation amplifiers, separate grounding of a body at a location as far away from the measuring electrodes as possible, and use of shielded electrode cable [9]. In many cases, narrow band rejection filter (notch filter) is implemented to provide sufficient suppression of line frequency interference.

Notch filter is known as band cut filter or band reject filter. It is used to remove some frequency portion of a signal. Simple notch filter circuit at 50 Hz has been added after the biopotential amplifier to eliminate power line interference. Based on equation (2), C_1 and C_2 are set to 47 *nF*, R_1 and R_2 to 10 kΩ and R_3 and R_4 to 68 kΩ calculated value is set the center notch frequency about 50 Hz.

$$F_{notch} = \frac{1}{2\pi RC} \tag{2}$$

$R = R_3 = R_4$; $C = C_1 = C_2$

Since this IA demand dual supply voltage, one 9 V battery, LP2985 and TC7660 used to produce ±5 V. In designing device related to human contact, the researcher should consider electrical safety concern as part of the circuit design. The circuit should offer protection of the patient from any hazard of electrical shock [1, 9-10]. However, this concern is less relevant for device with battery powered (3-15 V) [3]. Therefore, there is no isolation circuit added to the circuit. Even so, parallel silicon diodes are added as low voltage breakdown which offer 600 *m*V transient protections as recommended in [10].

2.2. dsPIC microcontroller

Microcontroller is a brain of the whole system designed. dsPIC30F4013 microcontroller has been chosen to control the EMG data acquisition system. dsPIC30F4013 microcontroller is a 16 bit microcontroller with built in simple DSP functions. This microcontroller also offers 12 bit ADC with up to 13 input channel and 16 words result buffers. The Universal Asynchronous Receicer/Transmitter (UART) function embedded inside the microcontroller is used to asynchronously communicate with the wireless transceiver. UART in dsPIC30F4013 offers full duplex operation, high resolution baud rate generator and frame error detection. Other than that, this type of microcontroller is suitable for EMG acquisition system since it can be set for 1.15 data format which enable to read negative signals reading. Else, dsPIC microcontroller also able to implement simple signal processing which embedded inside the controller.

High resolution 12 bit ADC offers by dsPIC30F4013 makes the small EMG signal detected can be read. Each channel used need to be attached to the input pin of the microcontroller. 13 input pin provided by the microcontroller makes the EMG channel can be accessed up to 13 channels. Besides, this type of microcontroller is low power consumption and comes in small package of surface mount.

2.3. Wireless module

The implementation of wireless network in medical area is not new. It helps to increase physical mobility and mobile access to the information. In medical field, wireless technology is safe to be applied. As a proof, Bayer College of Medicine, Houston, Texas and Nottingham University have tested wireless technology in their monitoring system. A 12-lead ECG waveform has been remotely monitored at Bayer College of Medicine, while wireless cardiograph via RF telemetry has been applied in fetal monitoring at Nottingham University. Both of the wireless application gave no significant difference in the result using wireless and traditional method. In addition, immediate accessibility of the monitoring result will leads to a reduction in treatment time.

X-bee is a RF module which was engineered to operate within Zigbee IEEE 802.15.4 protocol and listed to operate in industrial, scientific and medical (ISM) band. It's a low cost and low power consumption wireless sensor network. Although it is developed for wireless sensor node application for remote monitoring, the RF module also can be set for point-to-point communication. Other than that, since the EMG signal may exist in 20 Hz-2 kHz frequency range, of course it requires higher data rate during signals recording to avoid aliasing.

3. System Architecture

The propose design of the system architecture will consist of wireless module layer, EMG channels layer, dsPIC microcontroller layer and power supply board layer. Each layer will be stacked each other. Microcontroller layer will be the brain of the EMG system where power supply, EMG channels and wireless module channel will be connected to the layer using flexible flat cable (FFC).

There are lots of advantages when using this system architecture. As the numbers of EMG channel used are varies according to its application, the main objective of stacking system is to allow users to vary numbers of EMG channels. By using stacking system, users are free to adjust the number of channels up to 13 as the microcontroller provides 13 input pin. Since surface mount component used in designing the EMG device, speciality in soldering the component is highly desired. Stacking board by layer and function as proposed give benefit of troubleshooting. Problems are easily to identify since each layer corresponding to one function only. Furthermore, it is more cost effective when there are parts broken in the circuit, only the part involved will be replaced. Any improvement on the system also can be made at the selected part without the need to replace the whole circuit designed with new one.

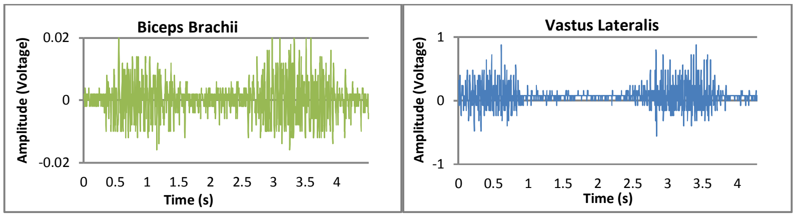
4. Results and Discussion

Result presented in this paper is the preliminary result since the system is still in development process. The result will be divided into two main sections; performance on EMG detection and the hardware of the acquisition system itself. To date, all the result is refers to one channel EMG system, especially on the EMG recording.

4.1. Performance on electromyography detection

Simple flexion and extension experiment on arm and leg have been conducted to record biceps brachii and vastus lateralis muscle activity using proposed architecture to investigate the ability in EMG detection. The EMG has been sampling at 500 Hz and baud rate of the microcontroller is set at 9600. The chosen of sampling is critical since it will involve filter order of the users intend to apply digital filtering inside the dsPIC30F4013. Higher filter order will lead extra memory space, especially when multichannel is applied. However, external memory like EEPROM can be added to solve the limited memory space problem. Other than that, higher sampling rate always desire since low sampling rate will introduce a delay and may affect the signals recording. Therefore, when digital filter added to the dsPIC microcontroller, there are many considerations to be made to ensure the original signals are not distorted and the further analysis is accurate.

Figures 3(a) and (b) show that EMG signals have been successfully detected in biceps brachii and vastus lateralis. The signals range is from -1V to 1V. Simple analysis of FFT in dsPICworks software by Microchip shows that the EMG is detected in frequency range of 10Hz and 60Hz as in blue circle in Fig. 4. It correlates to the literature where the strong energy existed within the frequency of 50 – 150 Hz. Furthermore, it also align with theory where the biceps brachii is contract when the muscle is in flexion condition and vastus lateralis is contract when the muscle is in extension condition [11].



(a) (b)

Fig. 3. EMG Signals; (a) Biceps Brachii, (b) Vastus Lateralis.

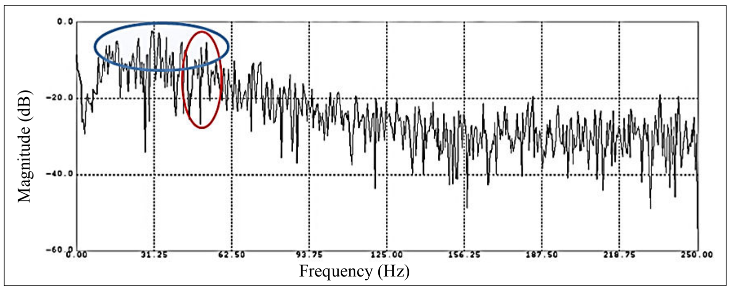


Fig. 4. FFT of EMG at Biceps Brachii.

Although notch filter added to the circuit design, it seems that the power line noise still exist in the recorded signals, and prove in the red circle show in the FFT waveform in Fig. 5. However, it very minimal compare to strong signals showed by EMG. To avoid baseline wander and potentially other biological response, a band pass filter is added to the system. As discussed before, digital filter will introduce some delay due to computation. Figure 6 shows filtered EMG signals for biceps brachii and Fig. 6 is show 0.04 seconds delay introduced by the FIR HPF.

4.2. Size, dimension and power consumption

For the preliminary design of the EMG acquisition system for one EMG channel is about 60 mm × 42 mm × 70 mm ($L \times W \times H$) dimension with estimated weight about 100 gram included 9 V cell. It include power supply layer, microcontroller layer, EMG channel layer and wireless module layer. Each layer of channel has estimated weight about 10 *g* with thick size of 1.6 mm. Power consumption of full system with one EMG channel is about 7.5 mA and each of EMG channel consume about 0.1 mA. Total power consumption of the device for one channel EMG is estimated about 67.5 mW.

Figure 7 shows the complete design of one channel EMG system. The spacing used to stack the board is about 20 mm. Therefore, each added channel will involve 20 mm spacing on height of the system. However, it totally depends on the spacing that user use since the thick of the board only 1.6 mm. As each board dimension is estimated around 28 mm × 36 mm × 1.6 mm, for future design we propose a parallel stacked since power supply board will be main platform of the system because it has the largest dimension compared to others. Parallel stack board will make the size and dimension of the propose system more reliable to be patched to human body as every added of two EMG channels only need one extra spacing of height.

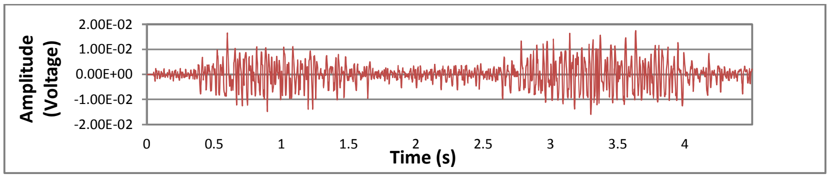


Fig. 5. EMG Signals at Biceps Brachii Filtered Using FIR BPF.

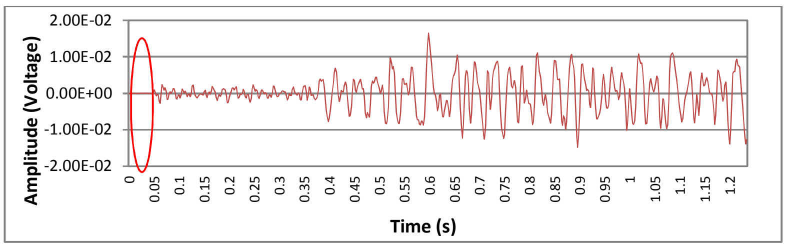


Fig. 6. 40 ms Delay Introduced by FIR HPF.

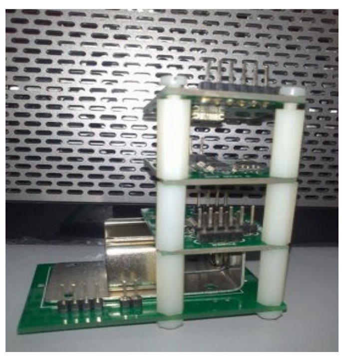


Fig. 7. The Low Cost and Wearable surface EMG Data Acquisition.

5. Conclusions

This paper proposes a low cost and wearable multichannel EMG data acquisition system. Results show that the system is successfully developed. Since the basic circuit design of biopotential amplifier used as the main concept of the architecture and no modification from original propose circuit by the manufacturer which need extra verification, the EMG signals is validated through the existence of the signals within 10-60 Hz frequency and the conditions when the muscle is contract based on theory. Although the result presented for two channels EMG, the propose idea on stacking system architecture can be adapted for multichannel EMG since it only programming in the microcontroller. Other than that, the programming also can be modified in order to get suitable filter, not distort EMG signals itself and minimize delay due to filter order. However, any extra components on active filter will only lead slight change of dimension and size of the circuit design since surface components are used. As the data acquisition system can be attached at human body and data is transmitted via wireless, many interferences can be avoided especially on movement artefact and noise introduced by the cable itself. Other than that, lot of further works can be done when wireless is implemented for example remote monitoring process where it suitable for rehabilitation process and sports training.

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