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Electromyogram (EMG) Signal Processing Analysis for Clinical Rehabilitation Application

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***Abstract* — Analysis of electromyogram (EMG) signal processing and its application to identify human muscle strength of rehabilitation purpose has been successfully carried out in this paper. Single channel EMG signal was obtained from human muscle using non-invasive electrodes and further process by signal acquisition circuit to get a suitable signal to be process. In the first part of signal acquisition, the amplification circuit for the small EMG signal has been design successfully. After amplification stage EMG signal was digitized through analogue and digital converter (ADC) then further process in microcontroller (ATmega328) for getting accurate EMG signal. Finally, the processed EMG signal was classified into 6 different levels in order to display the muscle strength level of the user. This EMG device can be used to help the weak person or an elderly to identity their strength level of muscle for clinical rehabilitation purpose.**

Keywords - Electromyogram; Non-invasive; Signal Acquisition.

I. INTRODUCTION

Electromyography (EMG) is the subject which deals detection, analysis and utilization of electrical signals emanating from skeletal muscle [1]. Electromyography is a very useful method in measuring muscle stimulation that has numerous applications in the diagnosis and treatment of diseases as well as the potential to enhance human abilities [3]. Electromyogram is a combination of electric and organism in our body where it is a diagnostic testing to assess the health of the neuromuscular action [2]. Nowadays, EMG is widely used in medical area for assisting weak or the elderly. However, due to very small range (μV to mV) of muscle signal, an instrumentation amplifier is vitally needed to amplify the signal as to avoid signal lost due to excessive noise build-up during data acquisition [4]. In addition, the signal obtained from the muscle will be different all the time and it would be a challenges for controller to perform well due to unstable signal information. Therefore, an accurate amplification circuitry is essential to be design and analyze appropriately [18].

In this project, non-invasive electrode was used to detect small signal from the muscles is more friendly-user instead of needle type invasive electrode [3]. The electromyogram circuit was developed to acquire useful muscle signal for rehabilitation purpose.

II. METHODOLOGY

The signal acquisition of EMG for clinical rehabilitation can be divided into several parts which are instrumentation amplifier, filtering, rectifier, analogue and digital converter (ADC), microcontroller and display unit. Fig.1 shows the general block diagram of the whole system.

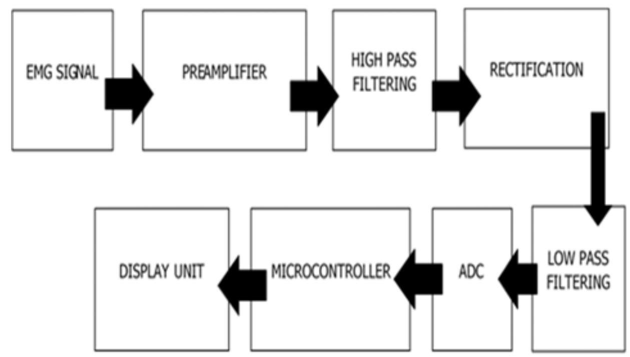

Figure 1. Overall system of EMG device

A raw EMG signal is obtained from the electrodes. Due to small range signal received from the muscle, high precision instrumentation amplifier are required to amplify the signal. Selected gain is required to amplify the signal to avoid the information signal eliminated for the next stage of the signal processing. Noise filtering are important in this signal processing to remove the noise. Hence, an active filtering circuit are used to avoid the offset voltage [17]. Precision full wave rectifier is important to rectify the signal for microprocessor processing purpose. A final stage signal amplification is necessary to amplify to the signal to microprocessor standard operating voltage signal. An analog to digital converter is paramount to convert the signal to digital for processing in microprocessor.

Finally, the converted signal will be processed by the microcontroller which is ATMega328. The output signal will be display in seven segment display and LED bar as an indicator for muscle strength level. The complete EMG signal acquisition circuit is as shown in Fig. 2 and the details explanation of each parts were discussed in following section.

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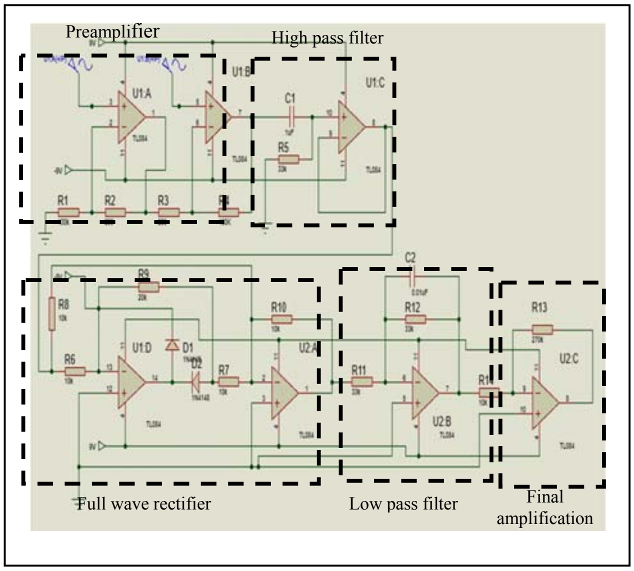

Figure 2. Complete EMG Signal Acquisition Circuit

A. *Preamplifier*

The instrumentation amplifier circuit as shown in Fig. 3 is used as a pre-amplifier to acquire EMG signal from muscle through the non-invasive electrodes [6]. Two operational amplifier (op-amp) was used to amplify potential different between two electrodes to a preferred voltage for controlling purpose [7]. Equation 1 is used to calculate the overall gain of the instrumentation amplifier.

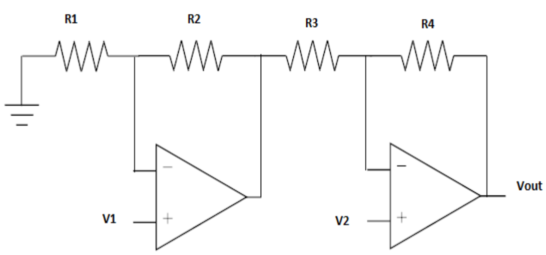

Figure 3. Two Op-Amp Instrumentation Amplifier

$$A_V = \frac{V_{out}}{V_2 - V_1} = 1 + \frac{R_4}{R_3} \quad (1)$$

B. *High Pass Filter*

Since the EMG signal obtained from the muscle has a lot of unwanted noise and offset voltage [8], it can affect the signal analysis and the following process. Thus, an active high pass filter is applied in the circuit to eliminate the offset voltage and reducing the noise [3]. DC offset was occurred is due to DC supply used and range between 0 Hz and 10Hz is suggested to remove the offset noise [9]. High pass filter will only allow the high frequency of the signal and block the low frequency signal [16].

C. *Rectification*

In this project, the precision rectifier is used rather than the normal rectifier. If the normal rectifier is used, the EMG signal to across the diode will be affected due to 0.7V forward bias voltage drop [7].

Generally, the EMG signal will be fluctuating in the range between positive and negative value during the muscle movement. The signal smoothing can be done after rectification. There are several types of rectification that can be done. But in this case, a full wave rectifier is used due to the muscle movement that has generated both the negative and positive value of the EMG signal [10]. If the half wave rectifier is used some information of the signal might be removed [14].

D. *Low Pass Filter*

Input signal to microprocessor is required to average in order to smooth the EMG signal. The process of smoothen the signal are using the active low pass filter. Low pass filter will only allow the low frequency and block the high frequency [11]. Hence, it able to smoothing the fluctuated EMG signal by using the low pass filter.

III. RESULT AND DISCUSSION

A. *Simulation EMG Signal in Protues(Software)*

Schematic and simulation EMG signal processing circuit have been done by using Protues (ISIS) software before tested in real circuit.

1) *Pre-amplifier*

The simulation for pre-amplifier circuit has been simulated using Protues software. The gain of pre-amplifier circuit was set according to the calculation.

Input value for both amplifier has been set to 300uV and 750uV ad frequency at 200 Hz. The input values has been shows in Fig. 4 which represented by Channel A and B respectively. The output signal of the pre-amplifier is represented by Channel C. It can be observed that the Channel C value has been amplified to approximate 250mVp-p. The suitable gain has been selected based on the equation 2 which is $A_v = 501$ [14].

$$A_V = \frac{V_{out}}{V_2 - V_1} \quad (2)$$

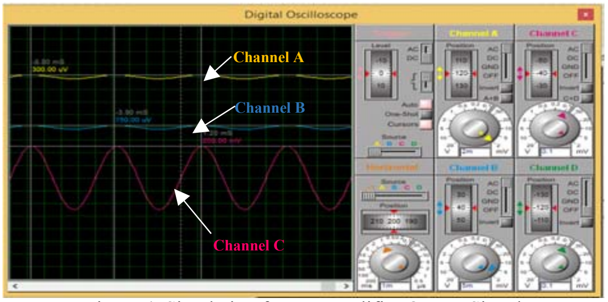

Figure 4. Simulation for Pre-amplifier Output Signal

2) High Pass Filter

High pass filter is designed to eliminate the DC offset. For the simulation, the frequency was set at 5 Hz due DC offset frequency range is between 0 Hz to 10 Hz.

A 3mV offset voltage was added into the simulation to ensure the function of active high pass filter circuit. As shown in Fig. 5. Channel C waveform is represent the signal before the high pass filter and Channel D represent the output signal after the filter. It can be observed that the offset voltage in the Channel C has been eliminated after went through the filter circuit.

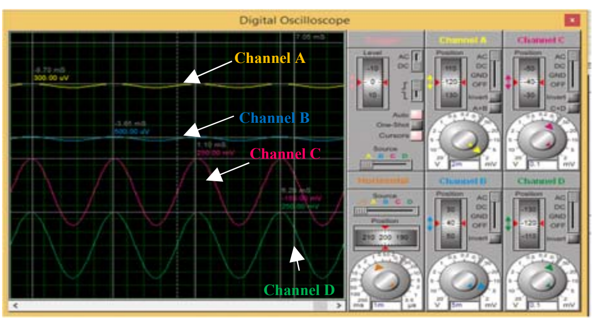

Figure 5. Simulation for High Pass Filter Output Signal

3) Rectification

After filtering, the EMG signal will be rectified by using a precision full wave rectifier. The precision rectifier was chosen because it suitable for accuracy measurement of the small signal.

Fig.6 shows that the simulation result for precision full wave rectifier. Output waveform of the high pass filter and rectified output waveform was represented by Channel A and Channel B respectively as shown in Fig.6. It can be distinguished the negative cycle wave was rectified to positive cycle without affect the signal information.

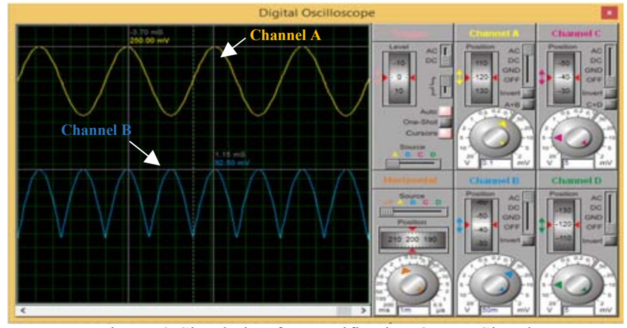

Figure 6. Simulation for Rectification Output Signal

4) Low Pass Filter and Final Amplification

After the rectification process, low pass filter and final amplification is required to enhance the information of the signal. Low pass filter is used to smoothing the fluctuation signal [15]. Channel A and B in Fig. 7 represent the output high pass filter and after rectification respectively. However, Channel C represented for low pass filter and final amplification simulation result.

An inverting low pass filter has been employed in this circuit which caused the output for the low pass filter was inverted to negative waveform. Hence, an inverting final amplifier was invented to amplify and the invert the output signal of the low pass filter waveform. The output voltage of low pass filter and final amplification is 1.6V.

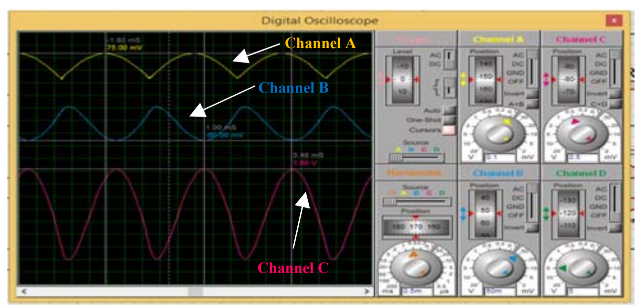

Figure 7. Simulation for Low Pass Filter and Final Amplification Output Signal

B. Experimental

EMG signal acquisition circuit was tested by using oscilloscope and multimeter to obtain the precise results and compare with simulation result. The electrodes placement should be at the suitable position to acquire accurate EMG value. Three electrodes are needed to obtain the EMG signal which two for positive electrodes and one for negative electrode as a reference.

A pre-experiment has been carried out to obtain an average input for muscle signal. Table I shows that the electromyogram voltage obtained from 10 students including female and male student by using electromyogram signal circuit. From the beginning of circuit design, the gain of pre-amplifier was set to 501 according to the calculation.

TABLE I. ELECTROMYOGRAM VOLTAGE DURING MUSCLE STRAIN

Student		Pre –amplifier (Voltage, V)			Final Amplifier (Voltage, V)		
		V1	V2	Avrg	V1	V2	Avrg
Female	F1	2.0	2.4	2.2	4.0	4.2	4.1
	F2	2.8	2.5	2.65	6.0	5.6	5.8
	F3	1.06	1.32	2.38	4.2	4.6	4.4
	F4	2.8	2.5	2.65	4.3	5.1	4.7
	F5	2.2	2.1	2.15	4.8	4.2	4.5
Male	M1	2.4	3.2	2.8	5.2	4.8	5
	M2	2.72	2.3	2.51	5.0	6.8	5.9
	M3	2.6	2.8	2.7	5.3	6.0	5.65
	M4	3.8	3.4	3.6	7.2	6.2	6.7
	M5	2.7	3.2	2.95	7.2	6.8	7.0
Average (Avrg)				2.66			5.38

From the Table I, it shows the average value of the output voltage pre-amplifier and final amplification is around 2.66V and 5.38V during muscle is fully strain. From the equation 3 below, the average input muscle signal obtained for 10 students is 5.30mV.

$$A_v = \frac{Vout}{Vin} \tag{3}$$

$$Vin = \frac{2.66}{501} \approx 5.30m$$

1) Pre-amplifier

Gain range in between 500 to 1000 is recommended to amplify the EMG signal [2]. Based on the calculation, gain = 501 was set for the pre-amplifier. Suitable gain is mandatory to avoid the information signal eliminated [20] .When there is no action or no strain on the muscle, there will be no signal or the signal is very small to be measured by the digital oscilloscope. The raw muscle signal when fully strained has been shown in Fig. 8. The maximum voltage for output signal with action is 837mV

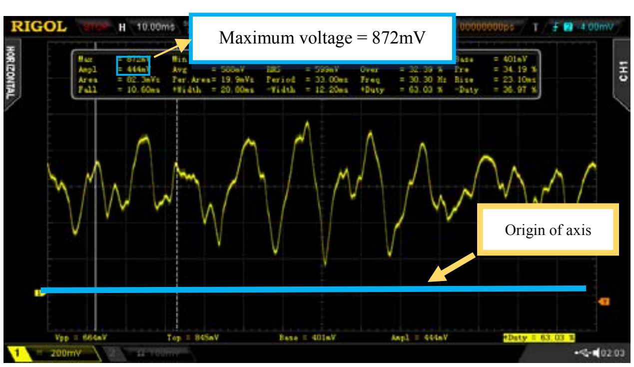

Figure 8. Output Signal of Pre-amplifier Circuit with Action

2) High Pass Filter

High pass filter is used to filter the DC offset voltage. DC offset is caused by the battery supply or supply from the adapter. It basically cause the signal away to origin axis .Due to this problem, the system may not obtain accurate values and will not perform well in the next output later.Fig.8 shows the EMG signal with offset value and Fig. 9 shows the output signal after the high pass filtering.

The offset filtering circuit has been tested frequently to ensure it working in good condition. It can be seen that the noise successfully filtered and returns to origin.

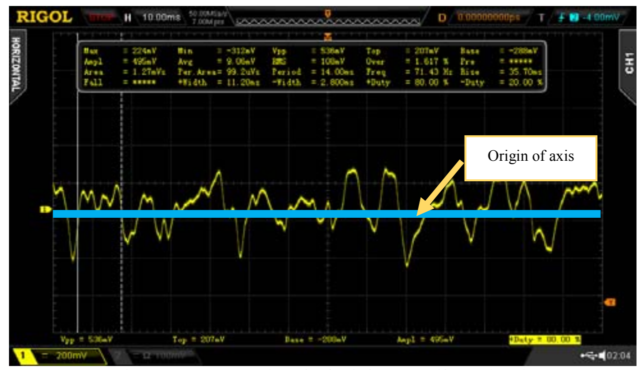

Figure 9. Output Signal of High Pass Filter Circuit

3) Rectification

Precision full wave rectifier is used in this project which is built by using op-amp. Full wave rectifier is used to prevent distortion signal which would cause a loss of some information of the muscle signal and avoid the negative signal to be eliminated [20]. Fig. 9 shows the EMG signal before passing through the rectification. The waveform of the output signal has both negative and positive components before passing through the precision full wave rectifier. Fig. 10 shows that the output signal after through the rectification stage.

The negative signal is remain and mirror to positive wave to positive wave to reserve the signal information. However, it shows that the signal consist of random noise even when there is no action. However, the random noise can be eliminates by using low pass filter [18].

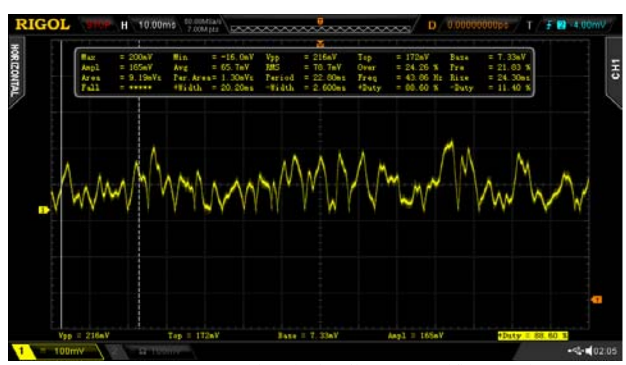

Figure 10. Output Signal of Fullwave Rectifier circuit

4) Low Pass Filter and Final Amplification

Random noise can be due to external effect including cable moving, contact gap between electrodes, electronics components and types of electrode used [16]. Hence, low pass filter can be used to smooth the signal and eliminate the noise.

As shown in Fig. 11, the output signal was smoothed when passed through the low pass filter. Meanwhile, the output of EMG signal was amplified to standard voltage which in between 0V - 5V. In this project, the final amplification gain was set as 250 to amplify the small signal to standard voltage. During the rectification process, the signal was rectified into DC signal. The signal after low pass filtering is shown to be almost flat. If there is no action, the voltage will be between 0 to 1.2V. This is because the muscle synaptic will transfer the signal continuously even when no movement occurs. If any movement occurs, the muscle synaptic will increase the potential difference during transmission of data [19].

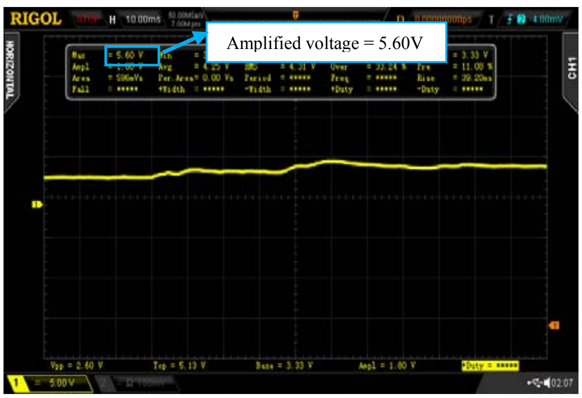

Figure 11. Output Signal after Low Pass filter and Final Amplification

C. Muscle Strength Level

The complete circuit was tested to observe the level of strength of muscle signal through the LEDs bar graph and 7 segment display. The range of level strength was referred to the voltage reference found in previous study [12]. The normalized muscle strength levels were classified into different level of strength and description [13] as shown in Table II.

TABLE II. MUSCLE STRENGTH LEVEL

Level Strength [13]	**Descriptions [13]**	**Voltage Range (V) [12]**	**Current Study Amplified Voltage Range(V)**
0	No contraction or muscle movement	0 - 0.0117	0 – 1.20
1	Trace of contraction, but no movement at the joint	0.0117 - 0.0583	1.20 - 1.66
2	Movement at the joint with gravity eliminated	0.0583 - 0.117	1.66 – 2.49
3	Movement against gravity, but no against added resistance	0.117 - 0.167	2.49 – 3.32
4	Movement against external resistance , but less than normal	0.167 - 0.347	3.32 - 4.15
5	Normal strength	0.347	4.15 - 5.0

Fig. 12 shows that the example of muscle level strength indicate by using LED bar and 7 segment display which is acts as an indicator or display unit for muscle strength level.

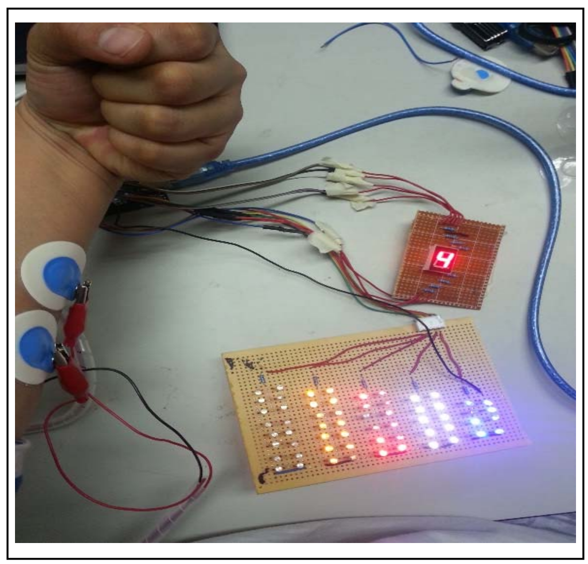

Figure 12. Muscle Strength level display

IV. CONCLUSION

The purpose of this EMG system is to help weak or elderly people to check their muscle strength level and acquire useful muscle signals for rehabilitation purposes. The EMG signal acquisition circuit has been successfully simulated using the Proteus (ISIS) software before the circuit developed. The EMG system consist of few major part; including a pre-amplifier, high pass filter, rectifier, low pass filter, analog to digital converter , microcontroller and a display unit. To ensure the performance, an experiment was carried out for 10 people with different gender. The simulated result and experimental result was compared and it has similar pattern for each element.

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REFERENCES

[1] Cram, J. R. and G. S. Kasman, 1998. "Introduction to Surface Electromyography", Aspen Publishers Inc., Gaithersburg, MD, pg 408.

[2] Konrad. Peter. 2005. The ABC of EMG: A Practical Introduction to Kinesiological Electromyography. Noraxon INC. USA. Retrieved 15 September 2014, from http://www.demotu.org/aulas/controle/ABCofEMG.pdf

[3] Scott Day, 2001. "Important Factor in Surface EMG Measurement. Engineering Design Guide and Environment". Retrieved 10 September 2014, from http://edge.rit.edu/edge/P08027/public/IRB/Paper/intro_EMG.pdf

[4] Hao, L., Shan, X., Peng, Y., Chen, L, 2010. "A Research and Design on Surface EMG Amplifier". IEEE 2010 Int. Conf. Measuring Technology and Mechatronic Automation, Tian Jin, 13-14 March 2010, 306-309.

[5] B.S Chan, C.L Sia, Farrah Wong, Renee Chin, Jamal A. Dargham, Yang Soo Siang, "Analysis of Surface Electromyography for On-Off Control", Advanced Material Research Vol.701,pp 435-439,2013.

[6] Chan Bun Seng, Farrah Wong ,2012 ."Myogram Circuit for On-OFF Control.", Proceesing of the 10th Seminar of Science& Technology 1-2 December 2012, Kota Kinabalu.

[7] Sedra, A.S. & Smith, K.C, 2003. Microelectronics Circuits. 5th Ed. Oxford University Press.

[8] Maheshwari, L.K., Anand, M.M.S, 2006. "Analog Electronics", Prentice-Hall of India (Private Limited). New Delhi. Retrieved 25 November 2014, from http://books.google.com.my/books?id=1NcSBP2OAQC&printsec=frontcover#v=onepage&q&f=false

[9] M. Karuna and Krishna Rao, 2014. "Design and Development of Physiological Signal Acquisition System", International Journal of Advanced Research in Electrical, Electronic and Instrumentation Engineering. Vol.3, Issue 7.

[10] De Luca, C.J, 2006. "Electromyography.Encyclopedia of Medical Devices and Instrumentation",John Wiley Publisher, 98-109.

[11] M.M.Shobaki, Noreha A.Malik, Sheroz Khan, Anis Nurashikin,Samnan Haider, Sofiane Larbani, Atika Arshad and Rumana Tasnim, 2013. "High Quality Acquisition of Surface Electromyography-Conditioning Circuit Design",5th International Conferences on Mechatronics.

[12] Huihui Li, Guoru Zhao, Yongjin Zhou, Xin Chen, Zhen Ji and Lei Wang, 2014 "Relationship of EMG/SMG Features and Muscle Strength Level: An Exploratory Study on Tibialis Anterior Muscles during Plantar-Flexion among Hemiplegia Patients", BioMedical Engineering Online. Vol. 13:5.

[13] Hugue Ouellete, 2008."Orthopedics Made Ridiculously Simple(Medmaster Ridiculously Simple)", MedMaster Inc.ISBN 0-940780-86-0

[14] Farrah Wong, Sia Chiew Lian, Chan Bun Seng, Lim Pei Yi, Renee Chin, Kenneth Teo, Ali Chekima, Khairul Anuar Mohamad, 2015 "Model Cart Control Using EMG Signal", 10th Asian Control Conference 2015, ASCC2015, pp. 1-4.

[15] Wonkeun Youn and Jung Kim, 2009." Development of a Compact-Size and Wireless Surface EMG Measurement System",ICROS-SICE International Joint Conference.

[16] Igor Luiz Bernandes de Moura, Luan Carlos de Sena Monteiro Ozelim and Fabiano Araujo Soares,2014. "Low Cost Surface Electromyogram Signal Amplifier Based On Arduino Microcontrolle".,International Journal of Electrical, Electronics and Communication Engineering. Vol:8 No.2.

[17] P. Geethanjali, Y.Krishna Mohan and P.Bhaskar, 2013. "A Low-Cost EMG-EOG Signal Conditioning System for Brain Computer Interface Application", International Journal of Engineering and Technology.

[18] Ullah K, Khan A, Ihtesham-ul-Islam and Mohammad A.U. Khan, 2011. "Electromyographic (EMG) Signal to Joint Torque Processing and Effect of Various Factors on EMG to Torque Model",Journal of Engineering and Technology Research Vol.3 (12).

[19] Aditya Veer Singh Rana and Ridhi Aggarwal. 2013. "2D Robotic Control Using EMG Signal", International Journal of Computer Application. Volume 72-No.14.

[20] A. N. Norali, M.H Mat Som, 2009."Surface Electromyography Signal Processing and Application: A Review", Proceeding of International Conferenece on Man-Machine System.