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Design and Implementation of an EMG Controlled 3D Printed Prosthetic Arm

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***Abstract*— Electromyography (EMG) is a biomedical signal which is recorded from muscle. It can detect muscle movements. By using HMI (human machine interfacing), EMG can be used to control prosthetic arms by an amputee individual. The available prosthetic arms and EMG signal recorders both are very expensive. The price of commercial prosthetic arm starts from 100,000 BDT. So, an affordable prosthetic arm is required for the people of Bangladesh. In this project an EMG recorder circuit along with a prosthetic arm was designed. The arm was printed using 3D printer and the recorder circuit was also printed in a circuit board (PCB) and built with available components. The 3D printed prosthetic arm was interfaced with the EMG recorder by Arduino microcontroller. The recorded signal was processed in both analog and digital domain. The arm was tested by an amputee individual who was able to control the prosthetic arm by muscle contraction which was detected by the EMG recorder. To minimize the cost, this project was completed using locally available resources. Total cost of this project was within 4,000 BDT. People who are amputee can use this 3D printed prosthetic arm to improve their quality of life.**

Keywords— EMG, Prosthetic Arm, HMI, 3D print, Amputee, PCB.

I. INTRODUCTION

In Bangladesh every year the amount of accident is increasing gradually. Due to those accidents people are losing their life or an important body part like arm and limbs. People's limbs are being amputee after getting injured. There are also infection and disease which cause amputation. Arm is a very important part of a human body because of its usefulness. Arm allows a person to touch, feel, grab things and also generate different gesture for communication purposes. Without an arm people has to relay on others for help or they have to manage their day to day live with great hardship. From year 2009 to 2016 almost 20,000 accidents occurred in Bangladesh. In the year 2017 almost 7,397 people died and 16,193 people got injured. And in year 2018 the number of deaths increased 7% from the previous year and 10,828 people got injured [1]-[3]. Due to injuries through accidents, infections or diseases like peripheral vascular disease, blood clots and diabetes thousands of people are being amputee every year. In this modern age due to human machine interfacing (HMI) has opened many opportunities. HMI is a technology where devices are capable of creating human machine interactions. Electromyography (EMG) is a biomedical signal which is generated by the movement of body muscle. It is an experiment-based method for evaluating and recording a series of electrical signals that emanate from body muscles. This signal is capable of detecting intentional muscle contraction. By detecting the intentional muscle contraction, it is possible to use EMG signal to control electronic prosthesis [4]. And 3D printing has opened opportunities to design and make 3D model of a prosthetic arm according to the patient's requirements.

There are some existing prosthetic arm theologies commercially available. Those prosthetic arms include Touch Bioinics, Open Hand Project, Bebionics, and Open bionics [5]-[8]. The price of those existing technology starts from $1,000 to $120,000 which is very costly for most of the people of Bangladesh.

There are some research projects as well. Those researches are of different categories. There is one category where the EMG recorder was in-house built and commercial or in-house built prosthetic/robotic arm has been used [9], [10]. Then there is another category where commercial EMG recorder has been used [11]-[18].

In this paper, we have designed and implemented both the EMG analog frontend and the prosthetic arm with locally available resources to minimize the cost as well as tested successfully with an amputee individual. The performance evaluation shows promising results to be used in developing countries like Bangladesh in near future.

II. MATERIALS AND METHODS

A. Analog Frontend

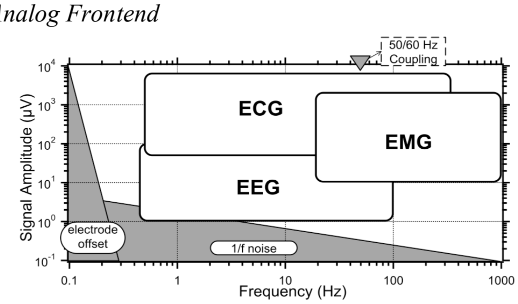

Fig. 1. Distribution of frequency and amplitude of different biomedical signals

Electromyogram is the combined action potential of the muscle cells of muscle tissue. EMG signal has amplitude of about 0.01mV to 1mV, and the frequency range is 20Hz to

1000Hz shown in figure 1. There are also some unwanted noises like 50Hz powerline noise, DC offset and other harmonics. So, the EMG signal has to be amplified and filtered. The amplification and filtering were done in analog domain. For the amplification AD620 instrumentation amplifier [19] and for filtering LM358 operational amplifier was used. The signal from the muscle is detected by the electrodes which are connected to AD620 through connecting wires. This was a single channel EMG recorder so only 3 surface electrodes were used to record the signal. The signal was amplified approximately 5000 times using AD620. The electrode position connecting to AD620 is illustrated in figure 2. The active filter specification used in the analog frontend is given in Table-1.

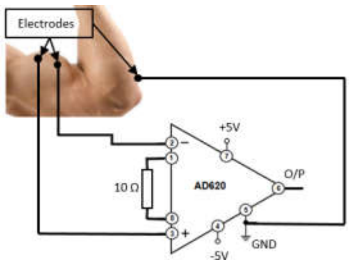

Fig. 2: Electrode position and connection to AD620

TABLE I: FILTER SPECIFICATIONS USED IN THE ANALOG FE

Filter type	Filter order	Cutoff frequency
High pass filter	2nd	4Hz
Low pass filter	2nd	1000Hz

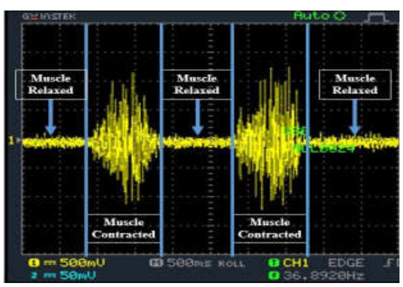

Fig. 3. Muscle contraction detected in the raw recorded signals observed on the oscilloscope.

The figure 3 shows the recorded signal when there is muscle contraction and when the muscle is relaxed. The signal still contains some noise.

B. Digital Signal Processing

After recording the signal, the signal was analyzed in MATLAB. The signal with muscle contraction and another signal without muscle contraction were plotted in frequency domain. Both signals contain 50Hz power-line noise and the signal with muscle contraction has the maximum power within 100Hz. So, the signal has to be filtered further to improve signal quality. For that the signal was processed in digital domain. Firstly, the signal was processed offline in MATLAB. After filtering the signal, the quality of the signal improved which is shown in Fig. 4 and Fig. 5 after applying digital notch filter (50-Hz) and low-pass filter at 100 Hz respectively.

The improvement was determined by calculating SNR of the signal. 5 different trials were taken and for each trial the SNR was calculated before and after filtering the signal. The results are shown in Table-II.

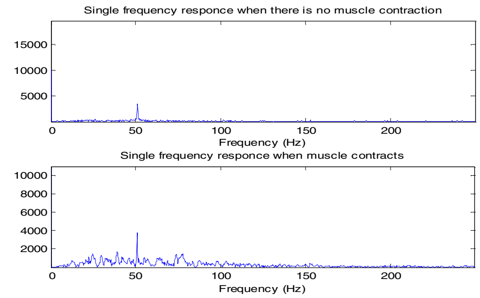

Fig. 4: Frequency domain representation of recorded EMG signals during muscle contraction and relaxation.

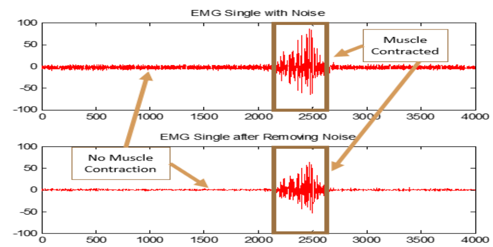

Fig. 5: Improvement in signal quality after removing background noise seen in time domain EMG signal

TABLE II: SNR BEFORE AND AFTER FILTERING

Trial No.	SNR with Background Noise (dB)	SNR after Filtering (dB)	Improvement in SNR after Filtering (dB)
1	38.0815	65.8975	27.8159
2	36.5238	65.1109	28.5872
3	39.1289	67.7473	28.6184
4	38.2893	66.6462	28.3569
5	42.0543	70.7411	28.6868
Average	**38.8156**	**67.2286**	**28.4130**

III. HARDWARE IMPLEMENTATION

The system has 2 different parts: EMG recorder and prosthetic arm. The recorder part is responsible for detecting muscle signal processing the signal and executing command according to the signal. And the prosthetic arm part consists of the mechanical design, actuators. The overall system block diagram is given in Fig. 6.

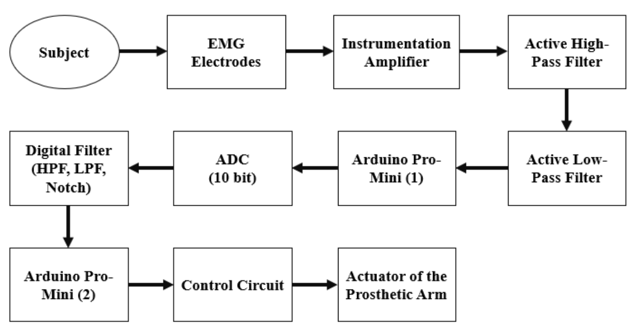

Fig. 6: Block diagram of the overall system used in this research work.

A. EMG Recorder

EMG recorder circuit was designed and simulated using Proteus software. And then the PCB was also designed in this software as shown in Fig. 7.

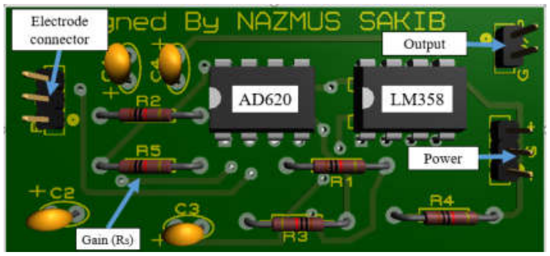

Fig. 7: 3D view of the PCB circuit with components

To power the recorder circuit, a dual power supply was used which contains a positive voltage, negetive voltage and ground. The electrode connectors were made using flexible copper wires and crocodile clips. The electrodes were gel type surface eletrodes. For the signal processing part an arduino pro-mini microcontroller was used. By using the filter cofficients from matlab digital filters were designed in the microcontroller to process the signal in real time. This microcntroller also detects muscle contruction and gives a signal whenever there is a muscle contruction.

B. Prosthetic Arm

There are many open source prosthetic arms designs available online [20]. Those designs can be modified/edited for the best interest of one's requirement. For this project an open source design was adopted and modified according to the requirements and it can also be modified further in future for improvement. The design was modified in 3D designing CAD software and later was printed using 3D printer. For the actuator, servo motors were used and individual fingers were connected by individual servo motors. The servo motors were controlled by an Arduino pro-mini microcontroller. Whenever the first micro controller detects a muscle contraction it gives a signal to the second microcontroller which controls the fingers. The 3D design and the printed arm are shown in Fig. 8 while in Table-III, the technical specifications of the printed prosthetic arm is provided. The complete set-up of the system is shown in Fig. 9.

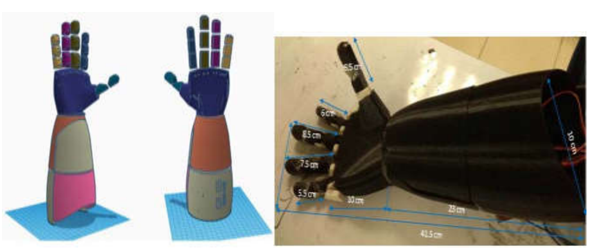

Fig. 8: 3D design of the prosthetic arm in tinkerCAD software (top) and prosthetic arm after printing (bottom)

TABLE III: TECHNICAL SPECS OF PROSTHETIC ARM

No.	Name of the part	No. of joints/parts	Length
1	Thumb finger	2	5.5 cm
2	Index finger	3	6 cm
3	Middle finger	3	8.5 cm
4	Ring finger	3	7.5 cm
5	Pinky finger	3	5.5 cm
6	Palm	1	10 cm
7	Wrist	4	23 cm
8	Diameter of the end of wrist	–	10 cm
9	Total length of the Arm	–	41.5 cm

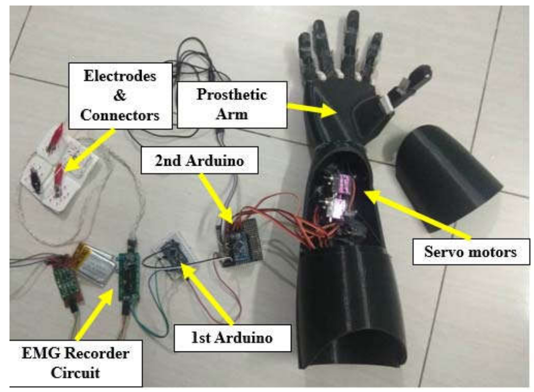

Fig. 9: Overall system overview starting from analog FE to prosthetic arm

IV. PERFORMANCE ANALYSIS

The prosthetic arms specifications are given in table. The table consists of the DOF, supply voltage, current & power consumption.

TABLE 1: SPECIFICATION OF THE WHOLE SYSTEM

Parameter	Value
DOF (degree of freedom)	5 DOF
Supply Voltage	5 V
No load current consumption	0.5A
Full load current consumption	2.6A
Full load power consumption	13W
Response time	1 sec (approximately)

The prosthetic arm was successfully controlled by an amputee individual as shown in Fig. 10. After that the arm was tested on 6 different healthy subjects to calculate accuracy.

Fig. 10: Experiment with the amputee subject controlling the prosthetic arm while trying to grab a small object.

There were 30 trials for each subject to calculate accuracy of the system. And with all the trials the overall system accuracy was approximately 87%. Each subject was asked to contract muscle to control the arm. For the first muscle contraction the fingers grab and for the second muscle contraction the fingers go to relax state. Whenever the subjects were able to control the arm then that trail was considered true and if any error occurs that trial was considered as false. The false trails are when there was muscle contraction but no action was executed and when there was no muscle contraction but some actions were executed. The result of the experiment is plotted in Fig. 11.

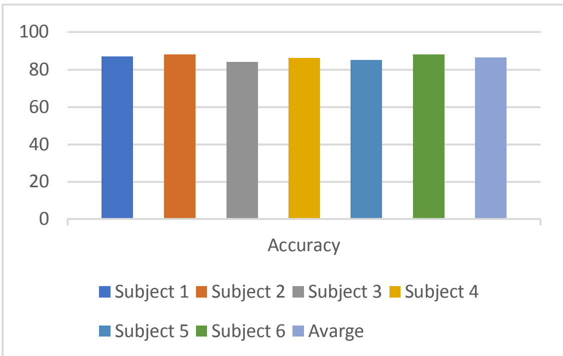

Fig. 11: Performance evaluation of the implemented system

The accuracy of the system can be improved by training the subjects more and by improving the circuit.

Overall the project was successful as it was tested on amputee individual and he was able to control the arm easily. But there are further improvements required to make this a commercial product.

V. CONCLUSSION

The Prosthesis is a way to improve the life of the people who are in some unfortunate circumstances. For a developing country like Bangladesh prosthesis is a very expensive solution. Most of the people in this country are living below poverty line. The people being amputee have to manage their life with great hardship as they cannot afford the prosthesis solution available in foreign countries. The foreign prosthesis is very expensive. This work introduces locally made prosthetic arm. The arm has already been successfully tested on an amputee individual. This arm is low cost and made by using local resources. The EMG recorder used in this work is also built in house. And the recorder can be used not only in prosthesis but also in diagnosis. The signal data from the recorder is assessable and the recorder design can be modified and developed locally. By having a local technology Bangladesh won't have to rely on foreign technology. Since the whole system is designed and developed here, so if any modification required, can be possible. Moreover, by getting Government subsidy or any NGO's fund will make the research project more economically viable.

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