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Development of A Low-Cost Real-Time Bioelectrical Signal Acquisition Module

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***Abstract*—Human Machine Interface (HMI) is gaining attention in the healthcare field and the acquisition of different bioelectrical signals simultaneously through one portable system remains still under active investigations, which can help further advancement of HMI. In this paper, we developed a system that can capture different respiratory signals (e.g. Electrocardiogram (ECG), Electromyogram (EMG) and Electrooculogram (EOG)) by utilizing low-cost hardware facilities in developing countries. The designed system was tested by capturing signals from human skin surfaces using electrodes. While developing such a system, we procured these signals by placing disposable skin surface electrodes on the desired positions of the body, employing customized electronic hardware. For computer interfacing and signal analysis, Arduino Uno was used in terms of Analog to Digital Conversion (ADC), whereas, a model developed in MATLAB Simulink for envisioning and saving the data in actual time. Our Simulink model designed using low-pass filters through the filter design toolbox selected different cut-off frequencies considering various bio-signals. Furthermore, a program is developed to store the signal data in MATLAB workspace for performing specific analyses. The developed prototype tested on human subjects proved to be efficient to integrate into assistive technologies.**

Keywords*—*Signal Processing, ECG, EMG, EOG, Biomedical Instrumentation.

I. Introduction

In the last decade, biomedical signal acquisition device development received much attention. Experts are striving not only to design models but also to enhance performance for this technology. Such materials, help carry out the regular diagnosis of essential variables of human anatomy, making assistive technologies for incapacitates [1].

A biomedical signal referred to as data in breathing organisms, can be observed continuously. This signal may be either electrical or not, which can be measured by a non-invasive process utilizing skin-surface transducers [2]. The human body generates various sorts of information. This information indicates the physiological conditions [3]. Among the electrical signals, Electrocardiography (ECG) is the method of creating an electrocardiogram – a diagram of voltage vs. time of the movement of the heart. Traditionally, the frequency range of the ECG signal is 0.05- 100Hz with a magnitude from 10μV to 5mV [4]. Electromyography (EMG) is an electro-diagnostic medicine process for evaluating the electrical activity produced by skeletal muscles, performed using an instrument to illustrate the electromyogram. Usually, the pulse of the EMG signal varies from 0-500Hz and amplitude from 0- 10mV [5]. Lastly, Electrooculography (EOG) is the process of producing the corneal retinal standing potential lying among the front and back of the human eye, resulting signal known as the electrooculogram. Approximately, EOG signal ranges between 15-200μV with a frequency of 0-30Hz [6].

In 2015, Nayak and others [7] developed an individual healthcare machine to read ECG, Phonocardiogram (PCG), and body surface temperature by customized software. Integrated Circuits (ICs) like instrumentation amplifier (INA128P), operational amplifiers (OP07CP, UA741CP), and passive components were utilized in their compound system for remote users to monitor cardiovascular conditions. The software NI USB 6009 Multisim and Ultiboard (v13.0) were employed for computer interface and analysis. In 2002, Tanaka and Knapp [8] used bioelectric signals (EMG) and relative position sensing) in the context of Human-computer Interaction (HCI) via music performance. Usually, EMG examines muscle action without movement (isometric) very well, but motion without a shift in pressure (isotonic) poorly. So, they suggested a multimodal communication system to enhance the input number to control, consequently the number of independent variables (bidirectional complementarity) that explains the interplay to overcome the inability of measuring isotonic movements. In 2012, Mello and Souza [9] exhibited a LabVIEW based virtual EOG analysis method, where Ag/AgCl electrodes were employed for data conditioning with a constrained accuracy and features. The EOG signals were augmented and refined using high-pass (0.5Hz) and low-pass (30Hz) filters, whereas, they used M Series USB-6221 as a signal recovery interface and amplitude-based allocation algorithm. Based on the magnitude of a blink signal is generally higher than any other motion of the eye, they examined the highest amplitude with an outset value, and when the amplitude crossed the outset, it was valued as blink.

In 2015, Ahamed and others [2] demonstrated a cheap wireless biomedical signal retrieval system for ECG, EMG, and EOG signals using Arduino Uno to visualize and store data in actual time. A model was also generated to store the data in a text file for further analysis in MATLAB. For their complex circuit design, Bluetooth serial communication was utilized to transfer the bio-signals containing moderate interferences.

The mentioned technologies offered limited functionality in regards to circuitry [2,7] feasible execution [8], precision with characteristics [9], and signal processing & filtering [2]. Besides, most of the available techniques need to be tuned manually, lack the advantage of digital filtration, and did not value accuracy in regards to affordability. Our primary goal of this research is to develop an affordable and high performing biomedical signal processor for people residing in remote areas. This designed acquisition module can digitally record and filter ECG, EMG, and EOG signals by placing electrodes at the appropriate positions of the human body.

The core contribution of this research work is enlisted below:

1. Development of an acquisition system for ECG, EMG, and EOG signals.
2. Algorithm development for Analog-to-Digital Conversion (ADC).
3. Establishing a Simulink model for digital filtration.
4. Executing a MATLAB program for spectrum analysis.
5. Testing the module performance for different subjects.

II. MATERIALS & METHODS

The proposed methodology contains four modules: power supply, electrical sensors, hardware design, and Simulink program in terms of MATLAB, whereas the flowchart of the designed system is shown in Fig. 1.

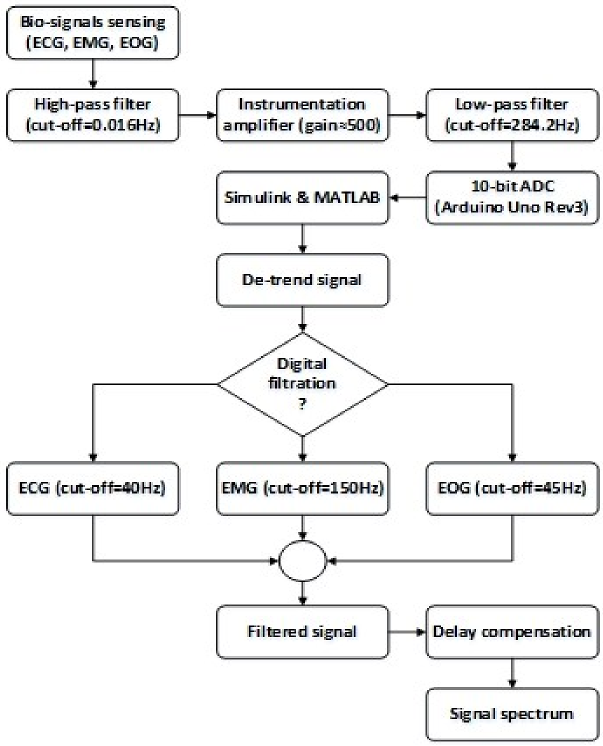


Fig. 1. Flowchart of the designed system.

A. Power Supply Module

Two commercially available 9V rechargeable Lithium-ion (Li-ion) batteries were connected in series as the power supply (Fig. 2a). Instead of providing 9V, the ±5V energy supply was generated by the two LM7805 voltage regulating ICs for short-circuit protection. For this system, the reference electrode needs to be attached to the 0V of the coupled supply followed by the ground (GND) connection [10].

B. Electrical Sensor Module

For receiving data from the skin-surface, non-invasive silver chloride (AgCl) surface electrodes were used as the electrical sensors (Fig. 2b). The electrical signal for a small group of muscle fibber cannot be detected using surface electrodes. But when a sufficiently large number of fibber act together, the compound superposition of all the signals close to the electrode can be received. Besides, the non-adhesive Velcro system led the electrodes (floating) to stay attached to the skin – removing any movement artifact. Here, the employed disposable electrodes, named Bio Protech T716, were placed using electrolytic gel between skin surface and electrode to reduce the impedance [11].

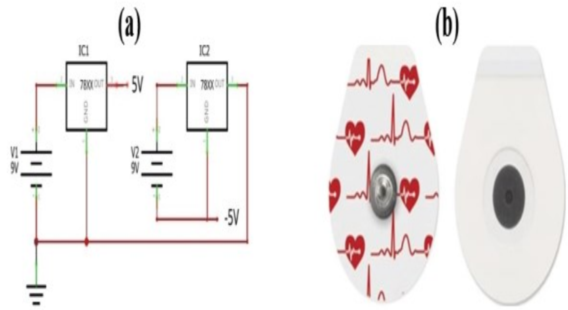


Fig. 2. (a) Power supply module, (b) Electrical sensor module.

C. Instrumentation Amplifier

Because a better EOG signal detection requires an amplifier to have a Common-mode Rejection Ratio (CMRR) more than 80dB, the system employed an economically available instrumentation amplifier, AD620 with a CMRR of 100dB at 1kHz [12]. A gain of about 500 was achieved by the amplification, which was set through using a 100Ω resistor (Rg). The gain formula for AD620 is given in equation (1) as follows,

$$Gain = \frac{49.7k\Omega}{Rg} + 1 = \frac{49.7k\Omega}{100\Omega} + 1 = 498 \tag{1}$$

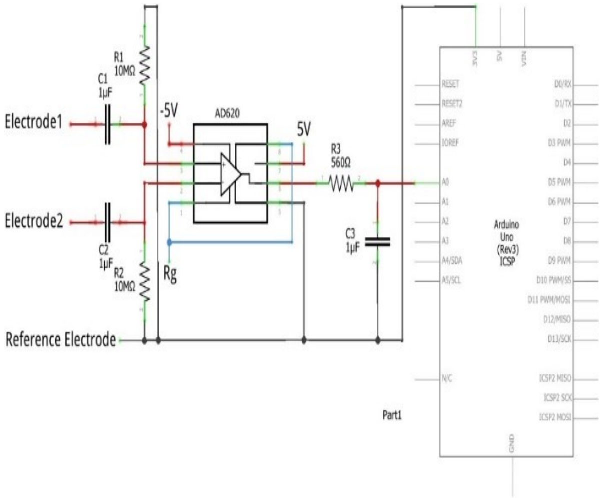
D. Passive Filters

For eliminating the low-frequency turbulences, a 1st order passive high-pass filter of 0.016Hz cut-off wavelength was employed before signal intensification by a 10MΩ resistor and 1µF nonpolar capacitor. After the amplification, a 560Ω resistor and 1µF capacitor were implemented as a passive low-pass filter containing a cut-off wavelength of 284.205Hz considering all the electrical signals. The cut-off frequency formula for passive filters is given in equation (2) as follows,

$$F_c = \frac{1}{2\pi RC} \tag{2}$$

E. Microcontroller Unit

Arduino Uno (Rev3) Integrated Development Environment (IDE) board with ATmega328 microcontroller was used for programming, which has a 6-channels 10-bit Analog to Digital Converter (ADC) and delivers a linear content between 0-1023 corresponding to 0-5V [13]. As the ADC functions within 0-5V, the 3.3V virtual ground was utilized to change the bipolar wave to unipolar. The serial transmission baud rate was chosen as 38400bps, and a sampling rate of 1270 samples/second was obtained.



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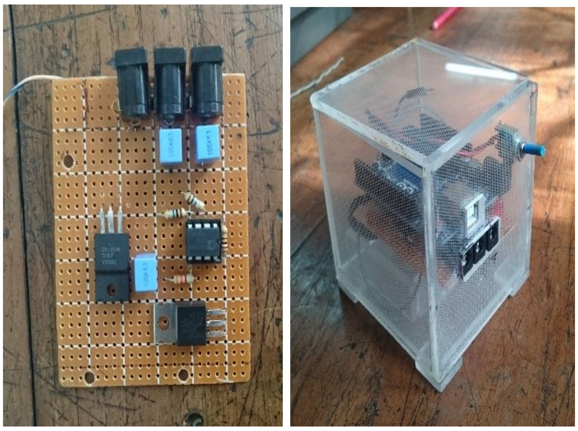


(b)

Fig. 3. Hardware design module (a) Schematic, (b) Prototype.

III. Software Implementation

The acquired real-time signals were visualized by the Simulink third-party support package for Arduino by selecting a sample time of 0.001 seconds. For digital filtration of the received signals, both Finite Impulse Response (FIR-Equiripple) and Infinite Impulse Response (IIR-Butterworth) low-pass filters used, where filter order was set to 100 for FIR filter along with sampling frequency of 1000Hz, passband amplitude at 1dB, and stopband amplitude at 80dB for both FIR and IIR filters were selected. In the case of ECG, a low-pass filter was chosen with a passband at 35Hz and a stopband at 40Hz. Where, for EMG, the passband set at 245Hz and stopband at 250Hz. Finally, in terms of EMG, the filter was selected with passband at 40Hz and stopband at 45Hz for both horizontal and vertical movement of the eye.

All the signals were de-trended to remove the baseline noise before performing the filtration. After the filtration, the delay caused by that was compensated. FIR showed comparatively good performance because of its higher-order and sharp cut-off response than the IIR filter. But FIR is hard to implement physically compared to the IIR filter that is why the MATLAB filter design advantage was taken. A program was designed to store the signals, thus, further processing such as spectral analysis was done [14]. Integrating different adaptive filter algorithms remain our future work to explore [15] [16] [17].

IV. Measurements & Results

For the visualization and storage of the ECG, EMG, and EOG signals, a laptop with Windows 8.1 Operating System (OS) – containing 2.5GHz Intel Core i5 processor and 4GB RAM utilized to perform Fast Fourier Transformation (FFT) for spectral analysis using MATLAB R2018a to store signals from the Simulink model. The exemplified signals acquired from 26 years aged subject (male); by fixing the AgCl surface electrodes on different positions of the body. Here, the ECG signal was achieved from lead 1 (+) - by two surface electrodes placed on the left (1) and right (2) arm and the reference (R) electrode on the left leg (Fig. 4a). Whereas, the EMG signal received by two electrodes (1, 2) placed on the bicep muscles of the left hand and the reference (R) electrode on the opposite side in between those (Fig. 4b). Lastly, EOG signal was obtained for the right eye by placing electrodes respectively, a pair (1, 2) was fixed on the side of each eye between the hairline to recognize horizontal motion, again the pair (3, 4) was fixed over and under the right eye to recognize vertical motion and the reference (R) electrode at the center of the forehead (Fig. 4c). All the subjects were required to sit in a fixed position for reducing motion artifact as possible.

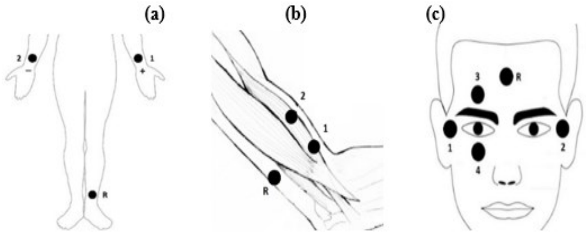
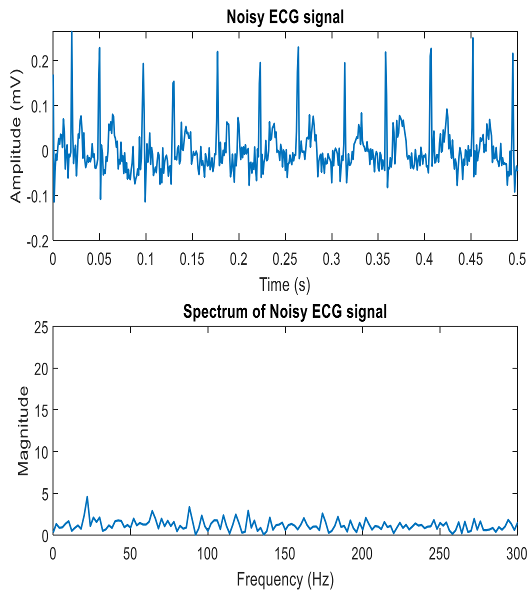


Fig. 4. Electrode placement for (a) ECG, (b) EMG, (c) EOG adapted from [18] [19].

Fig. 5(a) illustrates the ECG signal and frequency spectrum from the signal processing module, which was contaminated due to power line interference [20]. And, Fig. 5(b) depicts the ECG signal and frequency spectrum after filtration – analyzed through MATLAB. It can be seen that most of the higher magnitude (0-3.12mV p-p) spectral lines lie between 0-35Hz.



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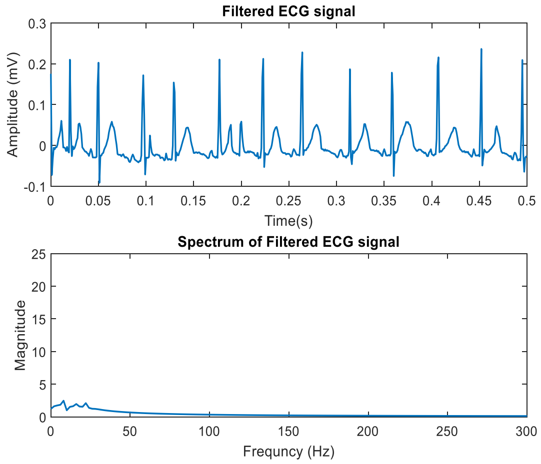
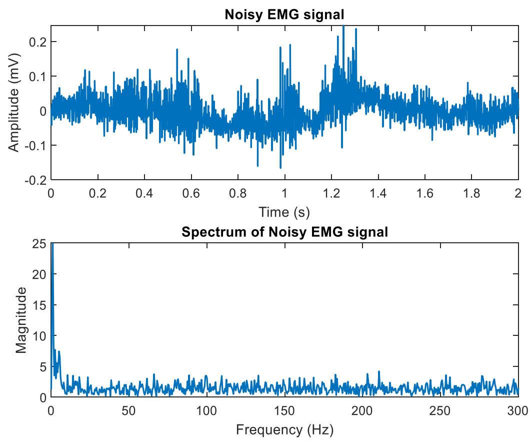


(b)

Fig. 5. Acquired ECG signal (a) Noisy, (b) Filtered.

Fig. 6(a) illustrates the EMG signal and frequency spectrum (existing slight interference) with an increasing peak (p) as the force of the muscles increased. And, Fig. 6(b) depicts the EMG signal and the frequency spectrum after filtration. It can be seen that most of the higher magnitude (0-2mV p-p) spectral lines lie between 0-140Hz.



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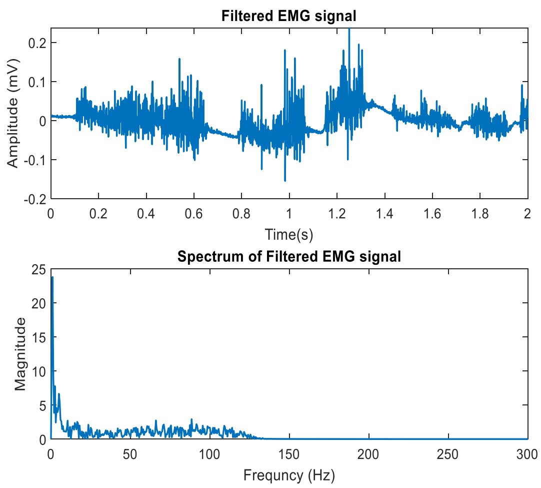
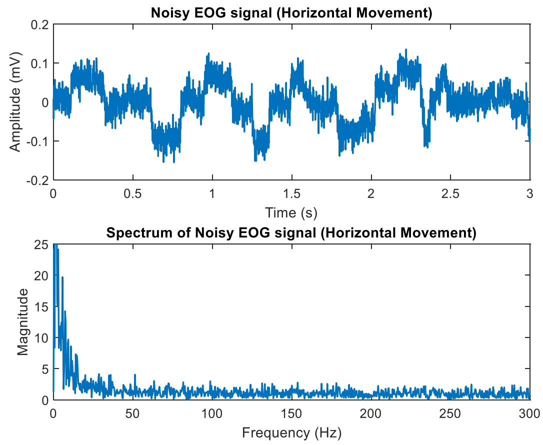


(b)

Fig. 6. Acquired EMG signal (a) Noisy, (b) Filtered.

Fig. 7(a) and 8(a) illustrate the EOG signal and frequency spectrum for horizontal and vertical eye movements, accordingly – showing a positive peak for the eye moves to the right and vice-versa. And, Fig. 7(b) and 8(b) depict the EOG signal and frequency spectrum after filtration. It can be seen that most of the higher magnitude (0-0.18mV and 0-0.15mV p-p) spectral lines lie between 0-35Hz and 0-42Hz, correspondingly.



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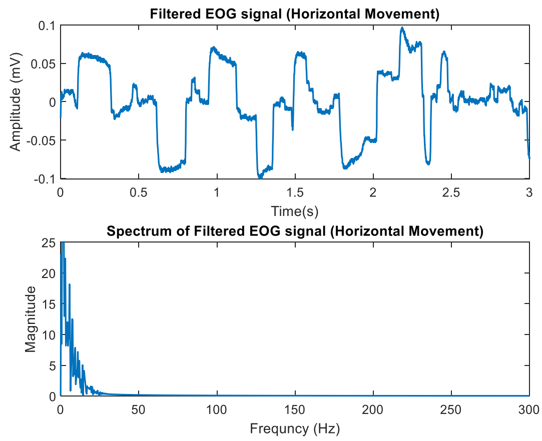

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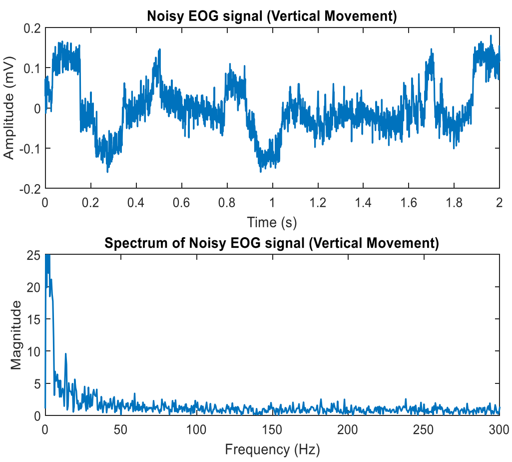
Fig. 7. Acquired EOG signal (horizontal movement) (a) Noisy, (b) Filtered.



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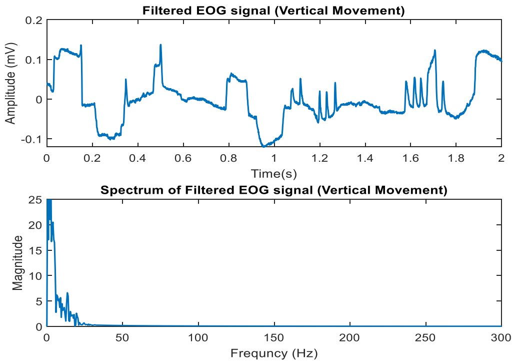

(b)

Fig. 8. Acquired EOG signal (vertical movement) (a) Noisy, (b) Filtered.

To reduce power line interference (50Hz), we utilized the laptop in battery-powered mode, carrying a little disturbance as well. Additionally, data analysis was completed in a closed room without any mobile devices to avoid interfering frequencies as much as possible. Here, some information regarding more test results for a different age group is represented in Table 1. The overall device expense demonstrated to be relatively cheaper than the existing models, as shown in Table 2.

Table 1. Signal analysis data of tests.

Signal Type	Age of Subjects	Frequency Range (Hz)	Voltage Range (mV)
ECG	14	0 ~ 30	0 ~ 2.50
	26	0 ~ 35	0 ~ 3.12
	48	0 ~ 38	0 ~ 3.18
EMG	14	0 ~ 130	0 ~ 2.10
	26	0 ~ 140	0 ~ 2.00
	48	0 ~ 140	0 ~ 2.15
EOG (Horizontal)	14	0 ~ 30	0 ~ 0.15
	26	0 ~ 35	0 ~ 0.18
	48	0 ~ 40	0 ~ 0.20
EOG (Vertical)	14	0 ~ 40	0 ~ 1.50
	26	0 ~ 42	0 ~ 1.50
	48	0 ~ 45	0 ~ 1.80

Table 2. The material cost of the method [21].

Specified Component	Quantity	Price (US$)	Aggregated (US$)
Arduino Uno (R3)	1	5.66	5.66
Instrument. Amplifier (AD620)	1	5.49	5.49
Voltage Regulator (LM7805)	2	0.12	0.24
Rechargeable Batteries (9V)	2	3.24	6.48
Electrodes (Bio Protech T716)	3	0.09	0.27
Resistors (10MΩ and 560Ω)	3	0.04	0.12
Capacitors (1μF)	3	0.02	0.06
Breadboard (mini)	1	0.06	0.60
Others	clips, wires, holders	estimated	5
Total	**-**	**-**	**24.19**

V. Conclusion

In this work, we tested the feasibility of constructing a low-cost bio-signal acquisition platform that can collect three important physiological signals (ECG, EMG, and EOG). Using the easily accessible digital filtration toolbox in Simulink provided the benefits of covering a wide range of frequencies, noise reduction, and sharp resolution. These biomedical signals were amplified with excellent gain value. The offset was correctly adjusted, giving stable signal amplifier outputs. Although this amplifier was developed especially for signal acquisition, its implementation is a function of what we choose, indicating a vast border on the usefulness of the device.

The electronic elements applied for this prototype absorb low energy, with the highest current of 50mA and functions around 24 hours by the battery-powered supply. Even taking necessary precautions, a slight noise detected in the acquainted signals due to the battery power line voltage, contact deflection between components, usage of typical cables, and random data of the environment. These problems might get resolved using an optocoupler circuit, developing a Printed Circuit Board (PCB) module, employing the co-axial cables, and shielding the designed circuitry. In this work, the EMG signals were collected from 0 to 250 Hz as most of the prominent signal information of bicep movements lies in this ranges and it can be possible taking a wide range of frequency after taking advantage of the digital filter toolbox selecting different cutoff frequencies.

In the upcoming fourth industrial revolution, we tend to implement an automatic system under artificial intelligence-based IOT infrastructure. The human biometric system, smart health monitoring system, and efficient user cooperative HMI will be an integral part of our society, where biosignal acquisition turns into a restorative procedure. Keep that in mind, and we try to develop a simple circuitry acquisition system at cheaper pricing, especially for the developing and underdeveloped countries. Our approach was to get the advantage by using MATLAB-Simulink signal filtration and visualization and build it compatible with other open-source platforms.

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