Wasit Journal of Engineering Sciences

Journal homepage: https://ejuow.uowasit.edu.iq

Development of a Low Cost Biosignal Acquisition System for ECG, EMG and EOG

Hassanein R. Mahmood[1], Manaf K. Hussein[1], Riyadh A. Abedraba[1]

Affiliations
Department of Electrical Engineering, Wasit University, Wasit, Iraq

Email:

hassaneinry@uowasit.edu.iq

Received
19-July-2022
Revised
10-October-2022
Accepted
24-October-2022

Doi: 10.31185/ejuow.Vol10.Iss3.352

Abstract:

The use of bio-signal is very crucial, providing enormous information concerning health and well-being of the individual. such signals can be measured and monitored by specialized devices to each bio-signal, for instance, the electrocardiogram (ECG), electromyography (EMG), electroencephalogram (EEG), and electrooculogram (EOG). Due to use of such devices, these signals could be utilized for several objectives. As it is observed in the devices of medical detection and Human to Machine Interactions (HCI). This paper presents a low-cost bio-signal collection device which is having the ability to record ECG, EMG, and EOG signals. Furthermore, STM32F103C8 system is used in Analog to Digital Conversion (ADC), with its particular application. An application has been developed in order to allow admins to observe and save the data signal simultaneously. This application has been developed by using C++ programming language and MATLAB's code. The data signal is recorded in a format of mat file, which can be studied in details in the proposed system. This system is capitalized on Universal Serial Bus (USB) wired communication link, which is used to transmit the bio-signal through, that guarantees the safety ,avoid noise and interference. The system shows its compatiblity with various operating systems, such as, Windows, Linux, and Mac.

Keywords: Bio-signal acquisition, ECG, EMG, EOG, Power line interference.

الخلاصة: يعد استخدام الإشارات الحيوية أمرًا بالغ الأهمية ، حيث يوفر معلومات مهمة تتعلق بصحة الفرد ورفاهيته. يمكن قياس هذه الإشارات ومراقبتها بواسطة أجهزة متخصصة لكل إشارة حيوية ، على سبيل المثال ، مخطط الاشارة الكهربائية للقلب (ECG) ، و تخطيط الاشارة الكهربائية للعضلة (EMG) ، و مخطط الاشارة الكهربائية للدماغ (EEG) ، و مخطط الاشارة الكهربائية للقلب (EOG). وكذلك اعتمادًا على استخدامها ، يمكن استخدام هذه الإشارات لعدة أهداف ، مثل الكشف الطبي والتفاعل بين الإنسان والآلة (HCI). يقدم هذا البحث جهازًا منخفض الكلفة لجمع الإشارات الحيوية و يتمتع بالقدرة على تسجيل إشارات ECG و EMG و EOG. علاوة على ذلك ، تم استخدام STM32F103C8 في التحويل التناظري إلى الرقمي (ADC) ، مع تطبيقاته الخاصة. تم تطوير تطبيق من أجل السماح للمستخدمين بمراقبة وحفظ البيانات في نفس الوقت. و تم تطوير هذا التطبيق باستخدام لغة البرمجة C++ و MATLAB. يتم تسجيل إشارة البيانات بصيغة ملف mat ، ويمكن دراستها بعد ذلك بمزيد من التفصيل. يستخدم النظام الاتصال السلكي Universal Serial Bus (USB) ، والذي يستخدم لنقل الإشارة الحيوية من خلاله ، لضمان السلامة وتجنب الضوضاء والتداخل. يوضح النظام توافقه مع أنظمة التشغيل المختلفة ، مثل Windows و Linux و Mac.

1. INTRODUCTION

In the last ten years, there has been a lot of focus placed on the development of the biomedical signal acquisition equipment. Not only are industry professionals, working to create models but they are also have been working to improve functionality of this technology. These materials contribute to the routine identification of important aspects of human anatomy, which paves the way for the development of assistive devices for disabled people [1]. The human body generates a variety of signals. Any signal in living creatures that can be continuously measured and monitored, it is classified as a bio-signal. Non-invasive bioelectrical signals might be detected using a skin-surface transducer which is often employed to acquire bio-signals (ECG, EOG, EMG, EEG) [2, 3]. Low-frequency signals like the ECG and the EOG are bipolar signals. The usuage range for an ECG signal is between 0.05 and 100 Hz, and its amplitudes could be between 10 microvolts to five millivolts, with a mean value of 1 millivolts [4, 5]. The EOG amplitude has varies from 50 to 3500 µV and a frequency range from DC to 50Hz [6]. The EMG signal amplitude is typically varies from 0-10mV (peak-to-peak) and its frequency from 0-500Hz [7]. EMG has a dominating frequency range of 50-150Hz [8]. The frequency information is included in such signals is very helpful in medical diagnosis. ECG is one of those signals, which might help with diagnosis; particularly illnesses and conditions that are associated with the heart diseases, such as cardiovascular disease, pulmonary disease, and unexpected cardiac arrest [9]. Clinically, EMG has been used to diagnose neurological and neuromuscular disorders [10, 11]. Medically, EOG has been used to detect eye-related diseases. Human-machine interface and control of different devices, which are another key, using EMG and EOG signals [12]. This paper is utilized to present Low Cost bio-signal acquisition system, easily equipped, for monitoring bio-signals for patients. Using of STM32F103C8 microcontroller and Tl084cnTexas Instruments Operational Amplifiers, in addition to the Matlab platform. In order to provide accurate reports, this platform is gathering analog data from the sensor, with the assistance of the datalogger over extended periods of time.

The paper are organized in seven sections. The first section is an introduction about the equipments of biomedical signal acquisition. The second section focuses on the related works of previous studies. The third section gives an elaboration on the methodology, relying on five modules: the electrode sensor, power supply module, instrumentation bio amplifier, passive filters, and the microcontroller unit. The fourth section discusses the significant of system architecture. The fifth section explains software implementations in achieving the objectives of the study. Section six shows the measurements and results. Section seven is the conclusion which recapitulates the main findings of the study.

2. RELATED WORKS

Many studies have been conducted by scholars concerned bio signals acquisition system for ECG, EMG, EOG. In this section, a discussion will be held regarding works related with gaining vitality bio signals within a real time, costless, and facility in preparation. The medical care system that is suggested by physicians helps to manage the physical state of patients whenever and wherever it could be carried out by using a computer which is connected with a smart device.

P.Kalaivani, et al. [13] designed a wireless data acquisition system used for remote monitoring patients. the proposed device uses an AD8232 ECG sensor for reading the electrical activity of the patient's heart and providing a healthcare system. This is done with the purpose of giving medical assistance. The data that is collected by sensors is processed by Arduino, and the resulting ECG output signal will be shown on a serial plotter or sent to a smartphone through a Bluetooth module for viewing there. Christoph Schlüter, et al. [14] design and construction of an armband to collect electromyographic (EMG) data from the upper arm. The purpose of the constructed prototype is to serve as a platform for research on EMG-signal processing, with the ultimate goal of providing a transhumeral amputee with reliable control over a prosthesis. A dependable low-noise circuit was created with the use of electric circuit simulations. In order to achieve the smallest feasible footprint for the device, all of the components are laid out on printed circuit boards. A microcontroller board is responsible for recording the data and then transmitting it to a computer, either through wire or Bluetooth, so that it may be processed. The rechargeable batteries provide the device ability to function wirelessly. The performance of a device was shown by a series of tests carried out on humans with able bodies. Md. Shah Kamal, et al. [1] designed a system that is able to record various biosignals, such as electrocardiograms (ECG), electromyograms (EMG), and electrooculograms (EOG). Disposable electrodes were used to collect signals from the surfaces of human skin. The signal was acquired by placing the electrodes in the required places in addition to using electrical circuitry that was specifically designed for this purpose. In terms of analog to digital conversion (ADC), an

Arduino Uno was used for computer connection and signal analysis. On the other hand, a model was constructed in MATLAB Simulink for the purpose of monitoring the data in real time. To chose varied cut-off frequencies a low-pass Filter have been used which was developed with the help of the filter design toolkit. In addition, the software is designed to be able to save data in the workspace of MATLAB so that particular studies may be carried out on the data. The prototype tested on human subjects and successfully integrated into assistive technology. Ahamed, et al. [15] created a low-cost wireless system for recording biomedical signals, as well as using an Arduino UNO to display and save data. After that, the stored data is sent to the computer via Bluetooth to be analyzed using MATLAB, which both guarantees their safety and significantly cuts down on noise interference. This system is compatible with Windows, Linux, and the Mac operating system, and it may run on either a portable or a stationary computer.

Our study aims to establish a high-performance, low-cost biomedical signal acquisition system for bio-signal processors. As part of this investigation, a device has been developed to acquire (ECG, EOG, EMG) readings. This article provides a prototype of a bio-signal acquisition system which is light in weight and can be powered by a USB connection. Electrodes are positioned in the right locations on a human body for this acquisition module so that it can digitally capture and filter the required signals.

3. METHODOLOGY

According to the suggested methodology, there are five modules it will be explained in this section: electrode sensors, power supply, instrumentation amplifier, passive filter and microcontroller. The developed system flowchart shown in Figure 1.

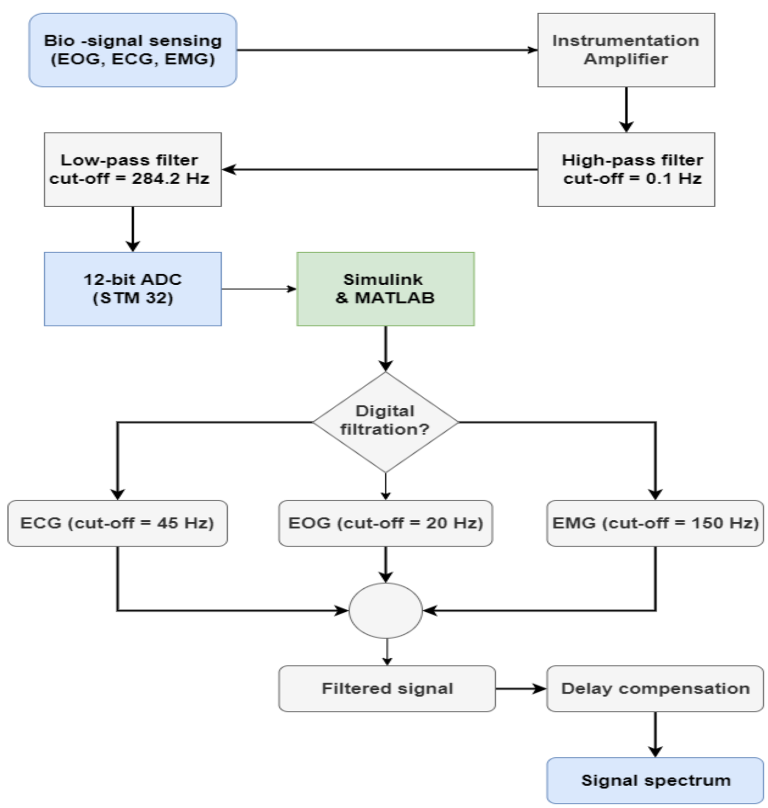


Figure 1. Diagrammatic representation of the system.

3.1. Electrode sensor

As it can be seen in Figure 2, surface electrodes comprised of (AgCl) which is called non-invasive silver chloride were employed in order to gather data from the surface of the skin. Surface electrodes are unable to pick up the electrical signal that is produced by a small cluster of muscle fibres because they are too far away. However, if a sufficient number of fibres cooperate, it is feasible to receive the compound superposition of all the signals that are near the electrode. This can only happen if the number of fibres is high enough. In addition, the non-adhesive Velcro technology ensured that the electrodes, which were free-floating, remained attached to the patient's skin during the whole treatment, therefore preventing the occurrence of any movement artefacts. In this study, the disposable electrodes used were termed Bio protech T716, and they were inserted between the skin surface and the electrode using electrolytic gel to minimize the impedance [16].

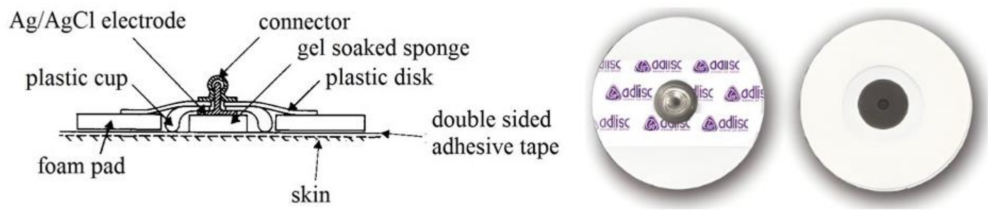


Figure 2. Bio-Protech T716 EKG monitoring foam electrode.

3.2. Power Supply Module

In this system, a dual rail power supply consisting of three terminals (V+, V-, and GND) is used. For this application, we will utilize a voltage divider circuit, and because GND is the reference voltage, we will get GND from the resistance between the two resistors that will be used as a voltage divider. The positive voltage supply is represented by the number Vin/2, while the negative voltage is represented by the number –Vin/2. This concept shown in the Figure 3.

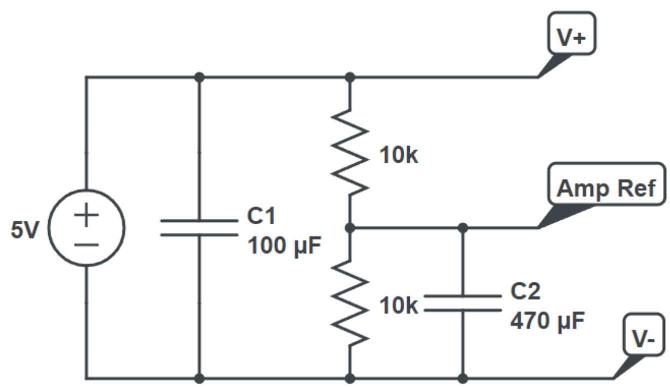


Figure 3. Resistor divider type virtual ground power supply

3.3. Instrumentation bio amplifier

The amplifier with a Common-mode Rejection Ratio (CMRR) of more than 80 dB required for enhancing EOG signal identification, a low-cost instrumentation amplifier was used that can be easily accessed. A suitable candidate for this system is the Texas Instruments TL084, which has quad low-noise JFET inputs and a high CMRR general-purpose operational amplifier [17]. The gain formula for Tl084 is described in equation (1).

$$Gain = \frac{49.4\ K\Omega}{R_g} + 1 \tag{1}$$

3.4. Active Filters

In order to reduce low-frequency turbulences, a 1st order active high-pass filter with a cut-off frequency of 0.1Hz was used prior to the signal being amplified by a 33kΩ resistor and a 47uF nonpolar capacitor. This filter has desired cut-off frequency. After the amplification stage finished, a active low-pass filter with a cut-off wavelength of 284.2Hz was made using a 560Ω resistor and a 1uF capacitor, which took into account all of the electrical signals [18]. The formula for determining the cut-off frequency of filters is provided in equation (2).

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

3.5. The microcontroller Unit

STM32F103C8 platform with ARM technology integrated development used as the processor in our system. As compared to other devices, the STM32 operates at 72 MHz, offering high performance and low power consumption, as well as real-time and low-cost capabilities. With a 3.3 V full-scale system, we have a 12-bit A/D converter with a conversion time of up to 1µs. The sampling rate can be set to be 100, 200, 500, 1000, and 2000 sps according to application needs (ECG, EOG, or EMG) samples per second. The overall circuit diagram shown in the Figures 4a & 4b.

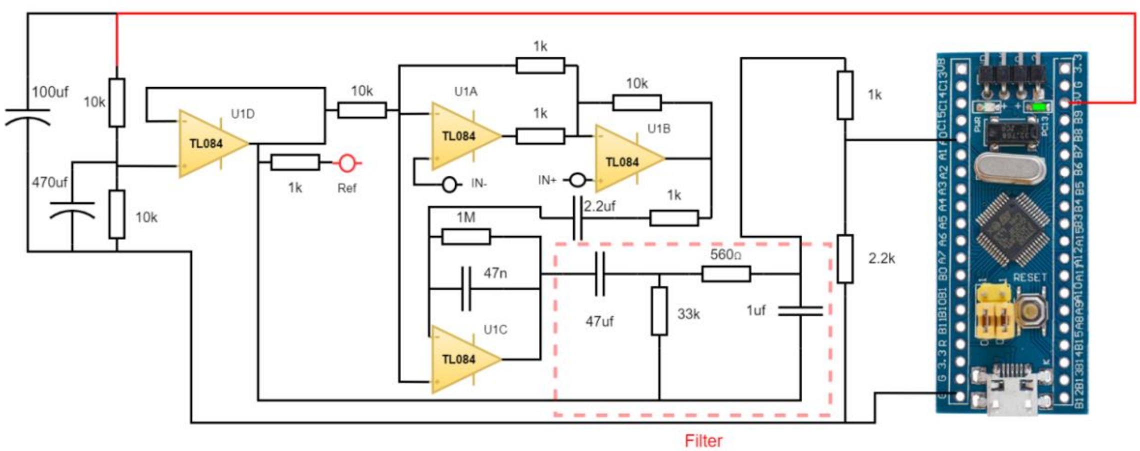


Figure 4. a. Overall Circuit diagram of the system.

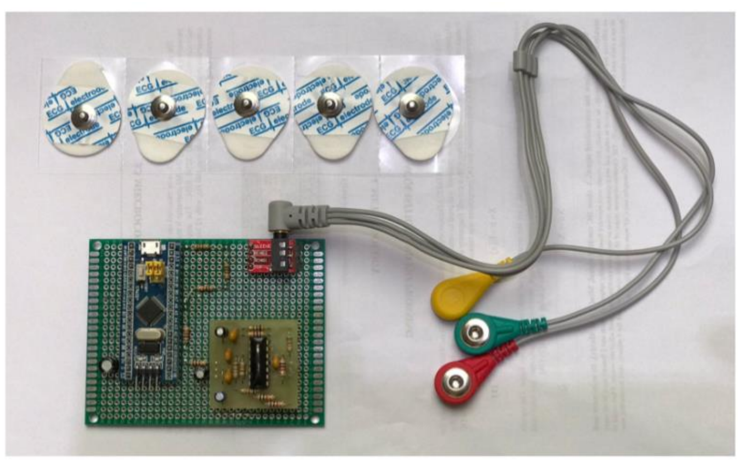


Figure 4: b. Hardware design and schematic prototype of the system.

4. SYSTEM ARCHITECTURE

The device uses three electrodes to acquire bio-signals. The overall structure of the system is shown in Figure 5. STM32F103C8 Microcontroller is used in this system for the purpose of analogue to digital conversion as well as signal transmission. Through this system, all vital signs (EOG, ECG, EMG) can be acquired via the electrodes. The electrode positions for the EOG, ECG, and EMG are shown in Figure 6.

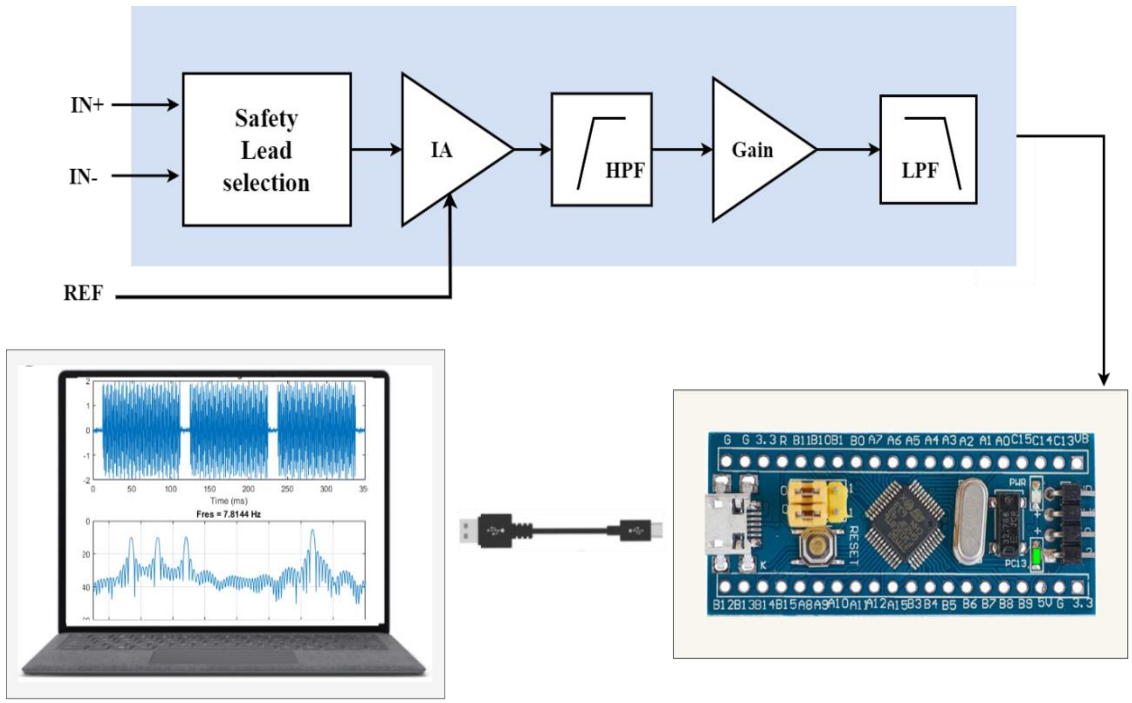


Figure 5: Overall System structure of the Bio-signal acquisition system.

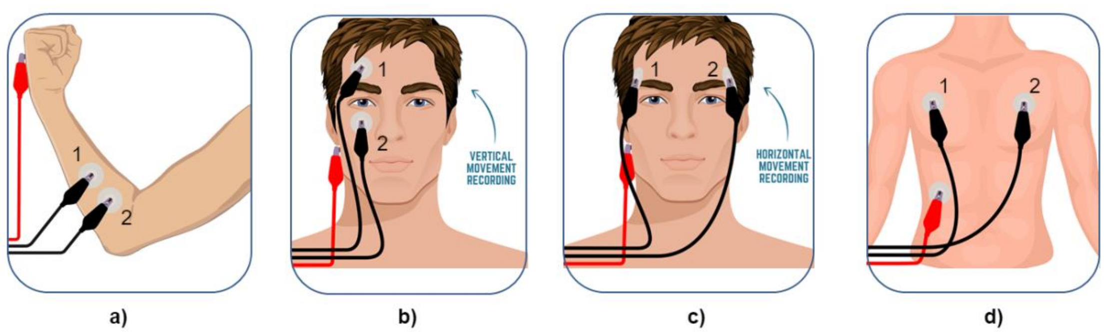


Figure 6: (a) The electrode position for biceps EMG limb leads and augmented, (b) The electrode position for vertical eye movement, (c) The electrode position for horizontal eye movement, (d) The limb leads for ECG [19].

5. SOFTWARE IMPLEMENTATION

Native programming language of MATLAB, which is C++ based, to implement the software. An integrated development environment, which is supplied by the STMcube IDE, is used for the purpose of programming the STM32F103C8 microcontroller. The infinite impulse response (IIR-Butterworth) low-pass filters were used to filter the received signals. The passband amplitude was set to 1dB and the stopband amplitude was set to 80 dB for IIR filters. With respect to ECG, a lowpass filter with a stopband of 45Hz was used. For EMG a filter with stopband at 150Hz was used. In order to record both the horizontal and vertical movements of the eye, the lowpass filters with stopband at 20Hz was used.

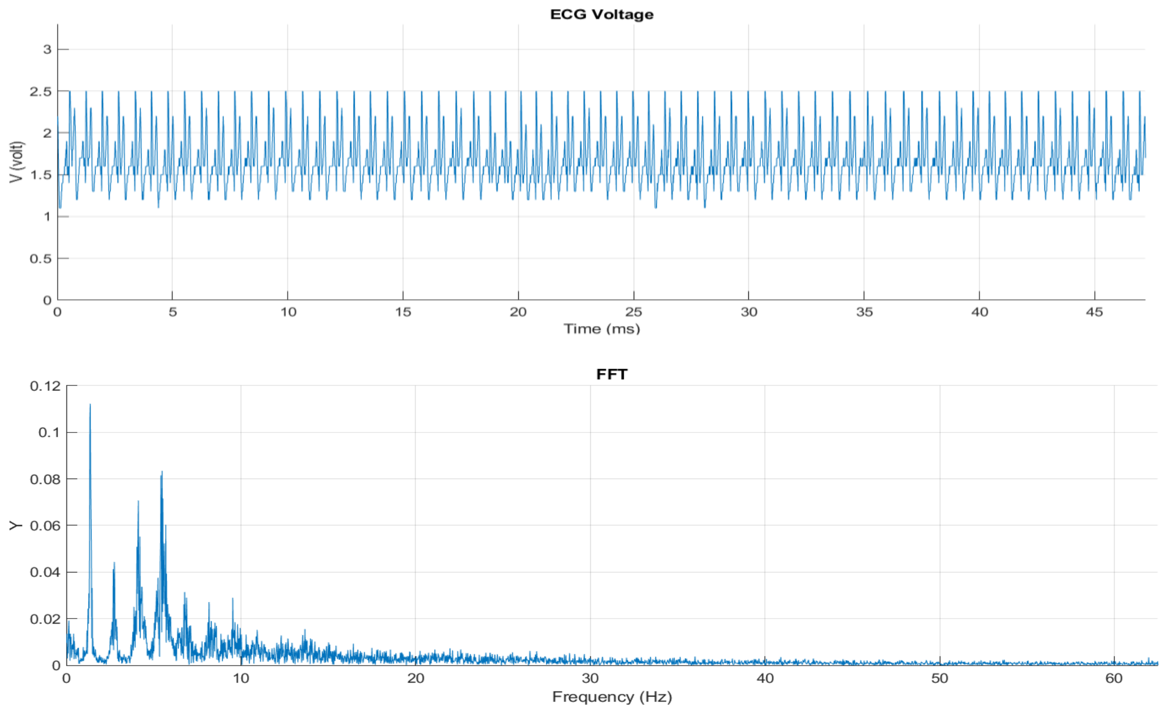
Each signal was filtered, in order to eliminate baseline noise before being processed via the filtering technique. The filter has been designed in MATLAB, which is an IIR filter instead of the FIR, because it is easy to apply physically. The software was created to save the signals for further processing, such as, spectrum analysis, that could be performed. Integrating several adaptive filter methods if they are needed for more examination objectives in the future.

6. MEASURMENTS AND RESULTS

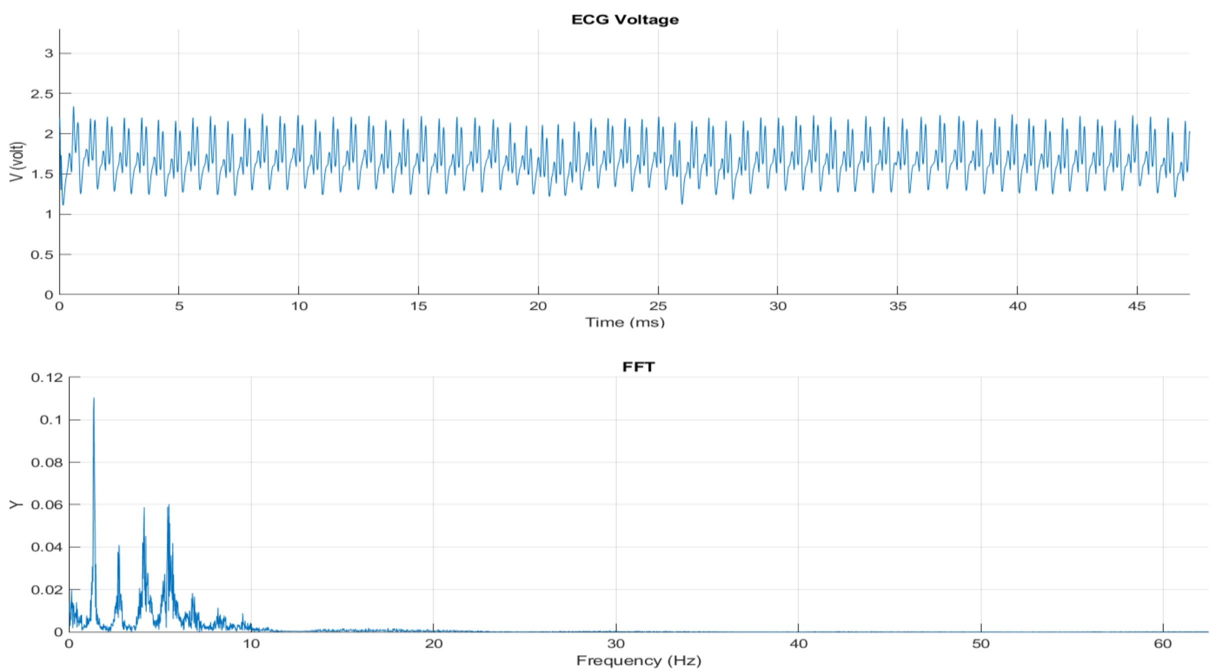
Figure 7 presents the practical measurement for the suggested device. A laptop with Windows 10 OS, 4.4GHz Ryzen 7 CPU and 16GB of RAM—was used in order to achieve the Fast Fourier Transformation (FFT) to the spectrum analysis and save signals. 10 healthy participants aged (24-45) Participate in the device inspection process. The signals were obtained by placing surface AgCl electrodes at the locations shown in Figure 6. The electrodes attached to the body provided the ECG signal. While the EMG signal was obtained by inserting electrodes (1&2) on the biceps muscles of both the left and right hand and the reference electrode (R) but at the other side between them, these electrodes were placed on the opposite side of the hand. In conclusion, an EOG signal was acquired for the right eye by positioning electrodes on the side of each eye to detect horizontal movement, a pair of electrodes (1, 2) above and below the right eye to detect vertical movement, and then a reference electrode (R) behind the ear.

Figure 7: presented the experimental measurements in relation to the horizontal EOG.

Figure 8(a) presents the electrocardiogram data as well as the frequency spectrum that was received from the signal processing module [20]. The ECG signal and frequency spectrum after filtering are shown in Figure 8(b), which was created by using MATLAB to evaluate them. This shows that the majority of larger amplitude spectral lines are located between 0 and 35Hz in frequency range.



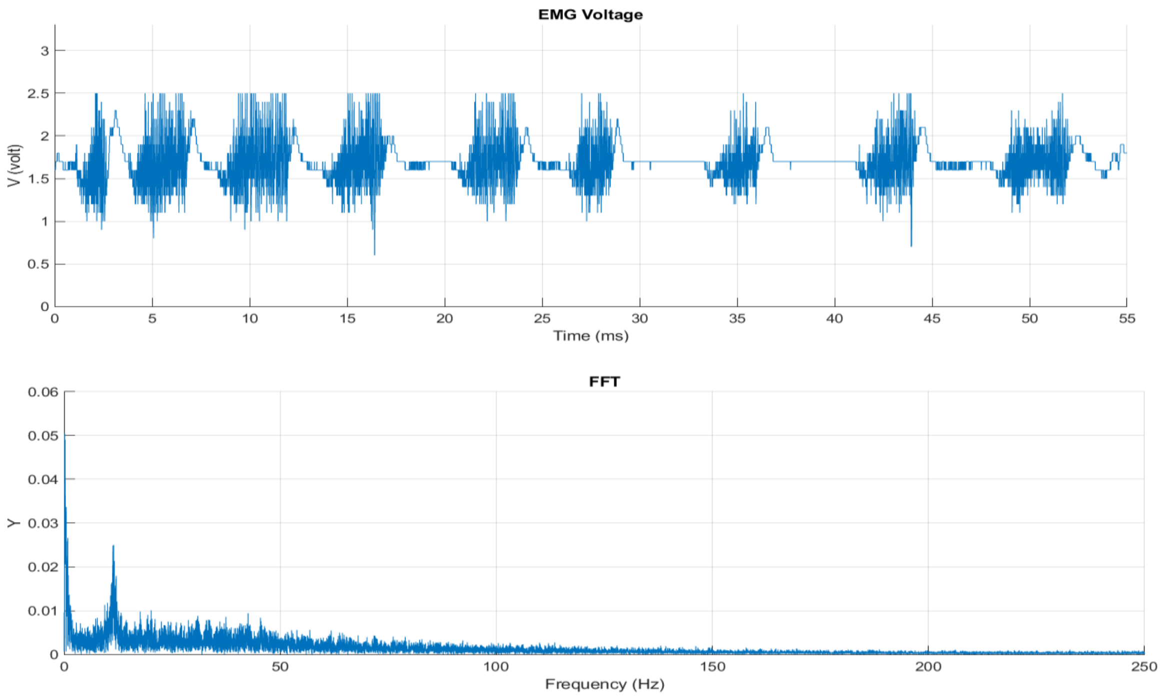
(a)



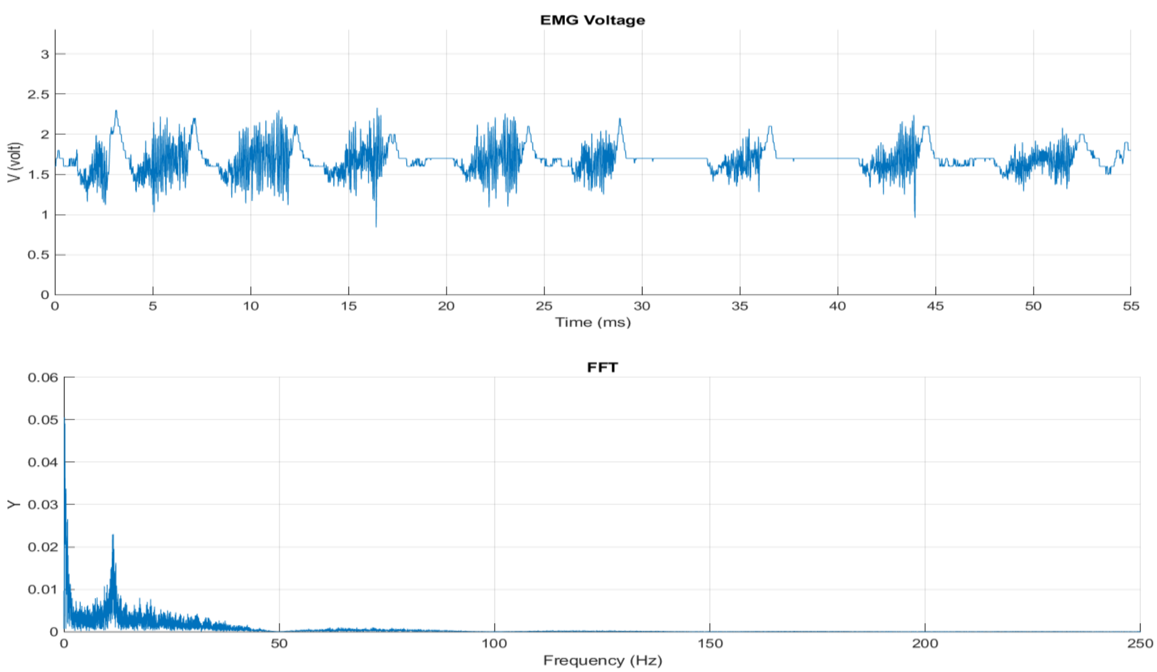
(b)

Figure 8: The acquisition ECG signals (a) before filtered, (b) after filtered.

Figure 9 (a) depicts the EMG signal and frequency spectra with some noise, showing a rising peak (p) as the force produced by the muscles increases. In addition, the filtered EMG signal is shown in Figure 10(b), together with its frequency spectrum, after the signal has been filtered. It can be noticed that the majority of the larger magnitude spectral lines are located between 0 and 150Hz in frequency range.



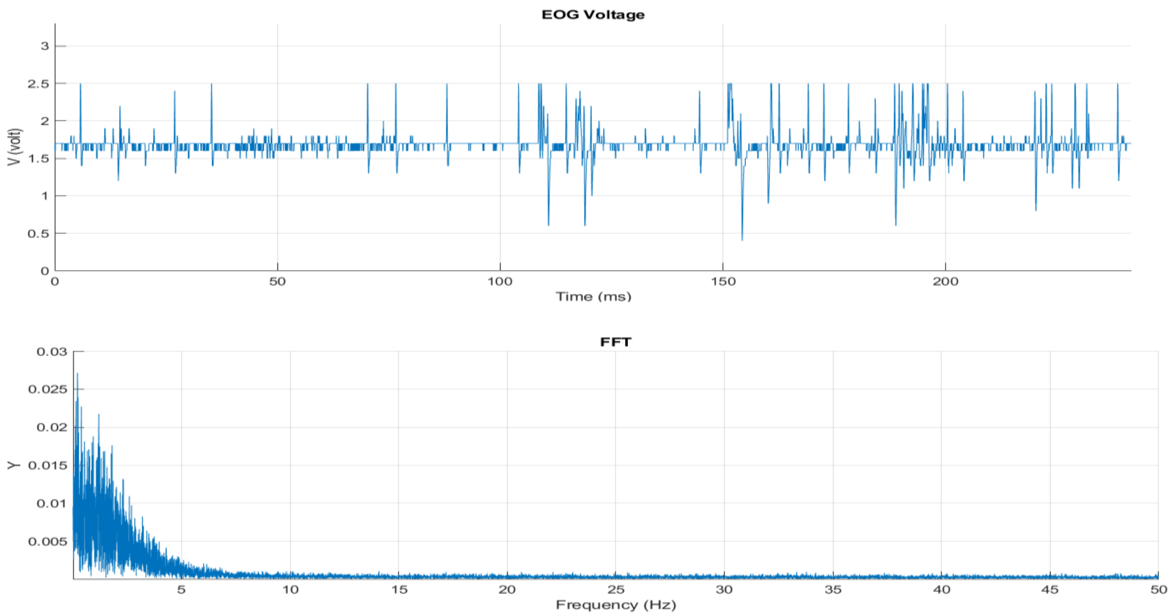
(a)



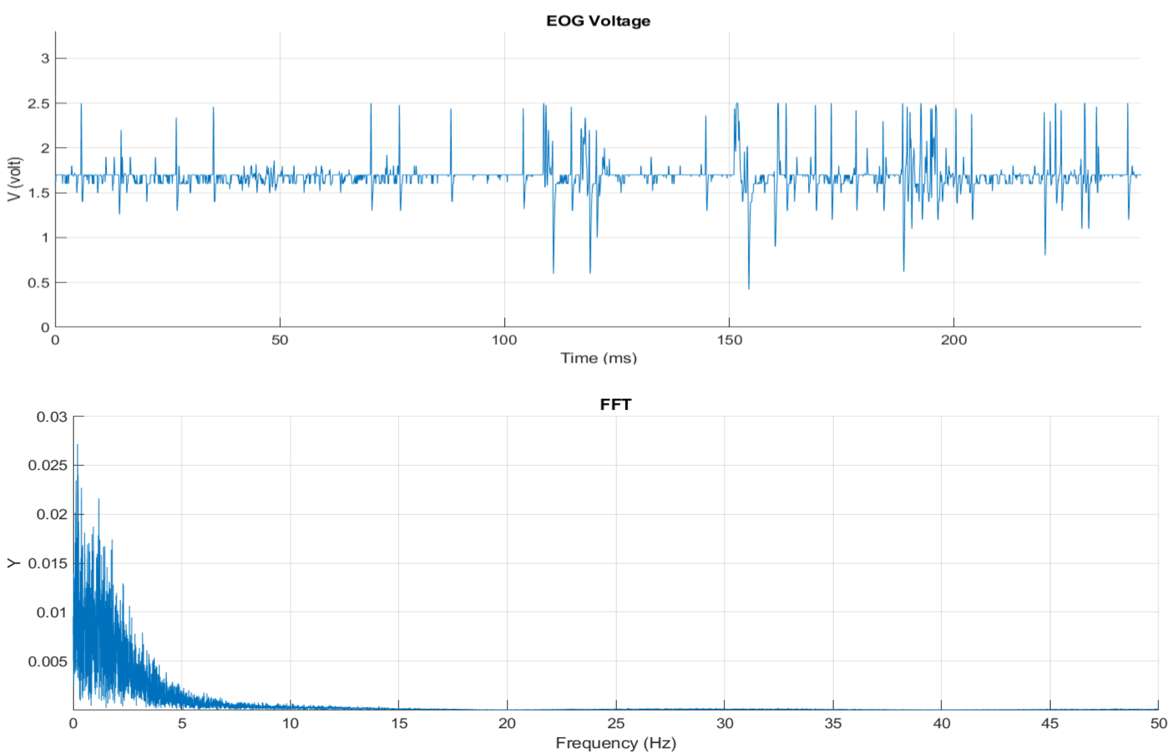
(b)

Figure 9: Acquired EMG signal (a) before filtered, (b) after filtered.

Figures 10(a), as well as 12(a), show the EOG signal and frequency spectrum for vertical and horizontal eye movements, respectively, with a positive peak for eye movements to the right and a negative peak for eye movements to the left. Figure 10(b) and Figure 11(b) show the EOG signal and frequency spectrum for eye movements to the left. In addition, the EOG signal, as well as the frequency spectrum after filtering, as well as the frequency spectrum after filtering can be seen in Figs. 10(b) and 11 (b). It can be noticed that the majority of the larger magnitude spectral lines are located between 1 and 20Hz in the frequency range.

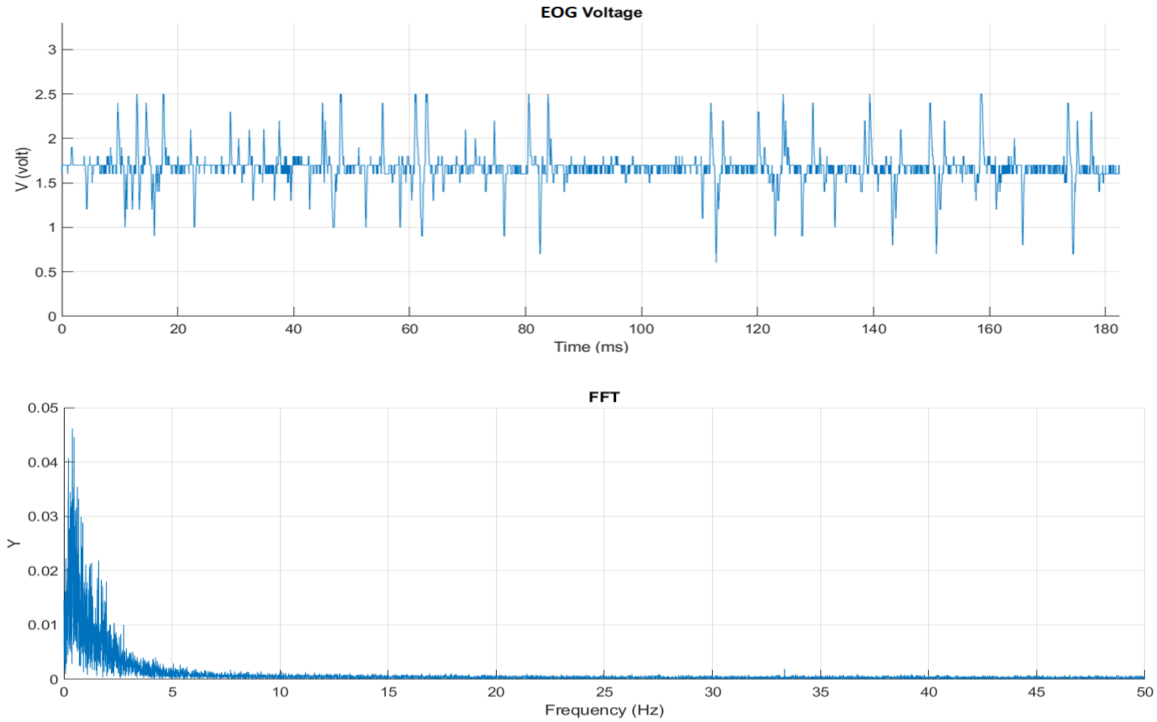


(a)

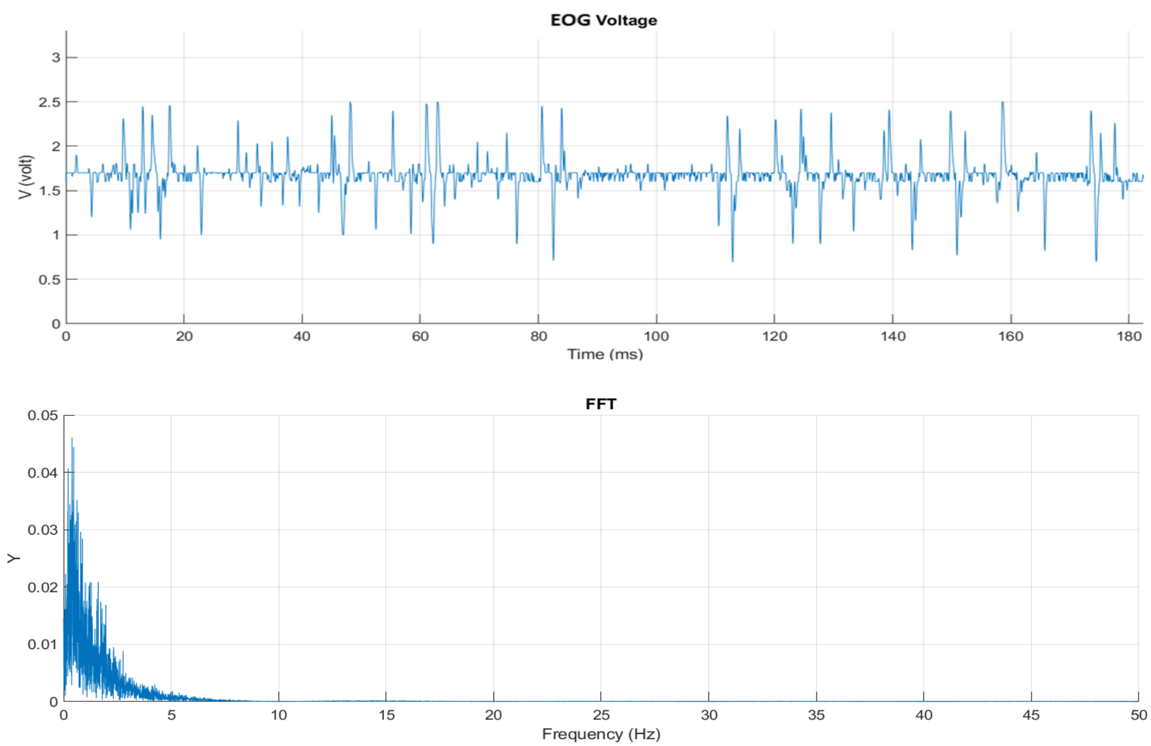


(b)

Figure 10: Acquisition EOG signal (vertical movement).(a) before filtered, (b) .after filtered.



(a)



(b)

Figure 11: Acquired EOG signal (Horizontal movement) (a) before filtered, (b) after filtered.

The proposed system accomplishes a major task by monitoring the patient's biosignals. The usage of a laptop in battery mode decreased power line interference (50Hz). The data analysis was carried out in a secure location that did not permit the use of mobile devices in order to prevent interfering with frequencies to the greatest extent feasible. As indicated in Table 1, the total device expenditure proved to be much less expensive than the previous versions. However, Table 2 illustrates the main differences between the proposed system and other related systems.

Table 1: The material cost of the system design.

Specified Component	Quantity	Price	Specified Component
STM32 (MC)	1	4.5	4.5
Instrument Amplifier (TL084)	1	0.5	0.5
Electrodes (Bio Protech T716)	3	0.02	0.06
Resistors and Capacitors	—	—	3
Breadboard (mini)	1	1	1
Others	Clips , Wire, Holder	—	10.94
Total	—	—	**20$**

Table 2: Comparison of the proposed system with related systems.

Parameter	P.Kalaivani, et al. [13]	Christoph Schlüter, et al. [14]	Md. Shah Kamal, et al. [1]	Ahamed, et al. [15]	Proposed System
Data Reading	ECG	EMG	ECG/EMG/EOG	ECG/EMG/EOG	**ECG/EMG/EOG**
Microcontroller	Arduino Uno	Arduino Nano	Arduino Uno	Arduino Uno	**STM32F103C8**
Transmission Technique	Bluetooth	Wire & Bluetooth	Wire	Bluetooth	**Wire**
Displaying Results	Serial plotter and smartphone	Computer	MATLAB Simulink	MATLAB Simulink	**MATLAB Simulink**
Time	Real-time	Real-time	Real-time	Real-time	**Real-time**
Cost Effective	Yes	No	Yes	Yes	**Yes**

7. CONCLUSION

In this work an attempt to design a Low-Cost Biosignal Device which is capable of capturing three essential bio-signal (ECG, EMG, and EOG). The use of digital filtering is crucial, having the benefits of covering a broad frequency range, reducing noise, and achieving sharp resolution. These advantages are all accomplished by utilizing the toolbox. The remarkable signal quality, resulted from the amplification of these biological signals with a high gain value, allows the signal amplifier to provide outputs that could be trusted. Although the fact is that the bio-signal amplifier is designed and constructed only for signals gathering, but its implementations depend on the sort of signal selected to achieve a specific function. It is observed that the benefits of the device has a wide range of possibilities. Moreover, the electrical components, used in this prototype, have a low power consumption rate, and the largest current can not exceed 80 mA, allowing it to operate for long time on battery. Despite implementing all essential safeguards, a minor noise is noticed in the familiar signals as a result of charging the battery of the computer. In this study, the EMG signals have been collected at frequencies ranging from 0 to 250 Hz. This is achieved because the vast majority of the significant signal information on bicep movements is located in this range of frequencies. It is observed that, it is possible to collect signals from a wide range of frequencies. By using the suggested program, the collecting of the biosignals (biometric) can be useful for health monitoring systems with low cost in comparison with other high cost devices.

References

[1] M. S. Kamal, E. T. Efaz, M. F. Alam, M. M. Rana, S. N. Sakib, and S. M. Islam, "Development of A Low-Cost Real-Time Bioelectrical Signal Acquisition Module," in 2020 *2nd International Conference on Sustainable Technologies for Industry* 4.0 (STI), 2020: IEEE, pp. 1-6.

[2] E. Kaniusas, "Physiological Phenomena and Biosignals," in *Biomedical Signals and Sensors I:* Springer, 2012, pp. 183-282.

[3] Y. Fu, J. Zhao, Y. Dong, and X. Wang, "Dry electrodes for human bioelectrical signal monitoring," *Sensors*, vol. 20, no. 13, p. 3651, 2020.

[4] A. M. Al-Busaidi and L. Khriji, "Digitally filtered ECG signal using low-cost microcontroller," in 2013 international conference on control, decision and information technologies (CoDIT), 2013: IEEE, pp. 258-263.

[5] R. B. Northrop, Analysis and application of analog electronic circuits to biomedical instrumentation. CRC press, 2003.

[6] A. López, F. Ferrero, D. Yangüela, C. Álvarez, and O. Postolache, "Development of a computer writing system based on EOG," *Sensors*, vol. 17, no. 7, p. 1505, 2017.

[7] M. K. Ulubas, A. Akpinar, O. Coskun, and M. Kahriman, "EMG Controlled Artificial Hand and Arm Design," *WSEAS Transactions on Biology and Biomedicine*, vol. 19, pp. 41-46, 2022.

[8] K. Yang, T. B. Meier, H. Zhou, G. S. Fischer, and C. J. Nycz, "A sEMG Proportional Control for the Gripper of Patient Side Manipulator in da Vinci Surgical System," in 2022 *44th Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC*), 2022: IEEE, pp. 4843-4848.

[9] M. Islam, G. Tangim, T. Ahammad, and M. Khondokar, "Study and analysis of ecg signal using matlab &labview as effective tools," *International journal of Computer and Electrical engineering*, vol. 4, no. 3, p. 404, 2012.

[10] A. Subasi, "Classification of EMG signals using PSO optimized SVM for diagnosis of neuromuscular disorders," Computers in biology and medicine, vol. 43, no. 5, pp. 576-586, 2013.

[11] T. Ahmed and M. K. Islam, "EMG Signal classification for detecting neuromuscular disorders," in *Journal of Physics: Conference Series*, 2021, vol. 1921, no. 1: IOP Publishing, p. 012043.

[12] M. Sarada, "Basics and Descriptions of Different Biomedical Signals," in AI-Enabled Smart Healthcare Using Biomedical Signals: IGI Global, 2022, pp. 1-25.

[13] T. T. P.Kalaivani, and G. V. P.Sindhuja, "Real Time ECG and Saline Level Monitoring System Using Arduino UNO Processor," A J A S T, vol. 1, no. 2, p. 5, 2017., 2017.

[14] C. Schlüter, W. Caraguay, and D. C. Ramos, "Development of a low-cost EMG-data acquisition armband to control an above-elbow prosthesis," in *Journal of Physics: Conference Series*, 2022, vol. 2232, no. 1: IOP Publishing, p. 012019.

[15] M. A. Ahamed, M. A.-U. Ahad, M. H. A. Sohag, and M. Ahmad, "Development of low cost wireless biosignal acquisition system for ECG EMG and EOG," in 2015 2nd International Conference on Electrical Information and Communication Technologies (EICT), 2015: IEEE, pp. 195-199.

[16] TELECTRODE, North American Headquarters : 14312 chambers Road Unit B Tustin, CA. 92780. [Online]. Available:https://www.hessamed.com/wp-content/uploads/2018/08/BIOPROTECH-ECG-Electrode12.12.14.pdf

[17] M. P. Gothwal, "ECG Signal Conditioning," *journal of medical science and clinical research*, 2016, doi: http://dx.doi.org/10.18535/jmscr/v4i1.10

[18] R. Raut and M. Swamy, Modern analog filter analysis and design: a practical approach. John Wiley & Sons, 2010.

[19] U. D. L. D. Khatri, "BioAmp EXG Pill," 2019. [Online]. Available: https://www.crowdsupply.com/upside-down-labs/bioamp-exg-pill

[20] L. A. a. S. D. Sordo, A. Brahme, Ed. Comprehensive Biomedical Physics. 2014.