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Arduino as an Educational Tool for Exploring Medical Signals

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Abstract

These days, gadgets of various kinds are an essential aspect of everyone's life. All these smart devices, whether they are watches, phones, rings, or wristbands, are built on basic sensors that allow us to continuously monitor our body temperature, heart rate, blood oxygen saturation, or sleep quality. There are numerous accessible, simple alternatives to these sensors, such as Arduino-compatible modules, which, configured properly, can build effective continuous monitoring systems. Students in the Faculty of Medical Engineering learn the fundamentals of medical electronics, which they can use in the class projects, bachelor's thesis, or at work. Since signal processing is the foundation of most applications and devices for monitoring vital parameters, this study proposes including a medical signal acquisition laboratory in the Arduino classes. In the theoretical section, students interactively discover medical signals, and then, in the practical section, they acquire, visualize, and measure them. To ensure the accuracy of the obtained signals, an advanced medical signal acquisition system, Biopac, is also used, and the outcomes are compared both visually and numerically.

Keywords: Medical signals, Laboratory classes, Arduino, Heart rate, Muscle contraction, Wearable sensors.

1. Introduction

The quality of education is constantly improving, particularly in the field of medical engineering, where hardware and software tools are used, and require the understanding of both the functionality of the equipment and the fundamentals of the recorded biosignals (Hernández-Delgado et al., 2017; Bañuelos-Mezquitan et al., 2025). The human body generates numerous biosignals that can be continuously measured and monitored (Ahamed et al., 2015). A proper acquisition, processing, and analysis of the recorded biosignals can provide relevant information about an individual's health and can be used for robot or prosthetic control, as well as a tool for automatic detections and physician diagnosis (Satiro et al., 2019; Ehrmann et al., 2022; Ahamed et al., 2015).

Nowadays, wearable devices have become an indispensable part of everyday life, allowing us to constantly track our vital signs, in addition to the professional devices found in hospitals and clinics. With the focus on education, new low-cost systems that perform the same functions as professional ones have been developed, providing students with an excellent alternative (Bañuelos-Mezquitan et al., 2025; Satiro et al., 2019; Delgado-Torres et al., 2024; Puente et al., 2017). With its many benefits, the concept of "Wearable Biosensor Technology", which is discussed by Hernández-Mustieles et al. (2024), has become increasingly integrated into educational environments.

The second-year students of the Faculty of Medical Engineering, National University of Science and Technology POLITEHNICA Bucharest, Bucharest, Romania, learn in the Arduino classes how to program various sensors used in the medical devices to read and write data. This study proposes incorporating a medical signal acquisition laboratory (**Figure 1**) that begins with a theoretical section, where students interactively discover medical signals (characterization of medical signals, wave morphologies, all the steps from recording the signals to an automatic detection or classification and exploring various devices and their applications). In the practical section, students use an Arduino UNO Board and specific sensors to record, visualize, and evaluate three medical signals: electrocardiogram (ECG), electromyogram (EMG), and photoplethysmogram (PPG). To ensure the accuracy of the Arduino-obtained signals, an advanced medical signal acquisition system is also used, called Biopac, and the outcomes are compared both visually and numerically, as it will be further described.

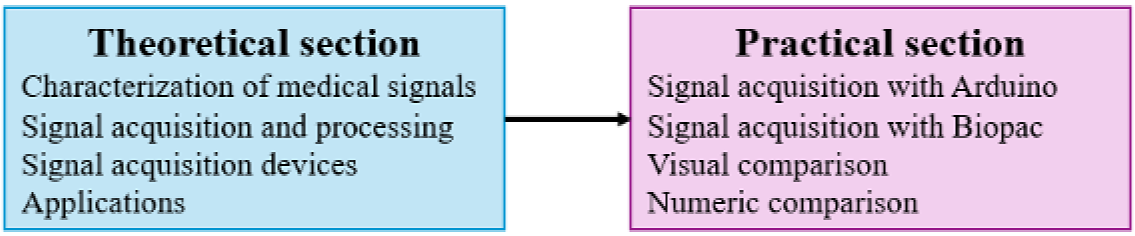

Figure 1. Block diagram of the proposed laboratory

This paper is structured into several sections that cover all the aspects of the laboratory. After a brief overview of the Arduino-based devices used in the educational process, the materials and methods necessary to develop this laboratory are described in terms of recorded signals, and acquisition and processing systems. Following the presentation and discussion of the results, several conclusions are made.

2. Literature Review

Numerous Arduino-based solutions are available to facilitate student laboratories, and a wide range of sensors are accessible to record various medical signals. In addition to its multiple software and hardware advantages, Arduino is compatible with other signal recording and processing software. Arduino boards are available in a variety of sizes and memory capacities, as well as sensors that can read various biosignals. Additionally, the Arduino IDE software is very user-friendly and intuitive.

Alsabah et al. (2023) focus on the design and implementation of a simple open-source medical sensor system for educational purposes, proposing an educational Arduino-controlled training board that includes many sensors and actuators (ECG, heart rate, motion processing unit, servomotor, DC motor, relay, and ultrasonic sensor), as well as a mini oscilloscope and LCD for data visualization. The proposed system was used by 87 students. A methodology for developing a low-cost prototype for acquiring and visualizing biosignals (ECG, EMG, galvanic skin response (GSR), and body temperature) is presented by Delgado-Torres et al. (2024). In addition to the sensors, an Arduino Nano board and a Bluetooth module to transmit the information wirelessly were used. Hernández-Delgado et al. (2017) also describe the design of a low-cost device that registers and displays ECG signals for educational purposes, which is based on the Arduino UNO board.

The model described by Satiro et al. (2019) measures three types of biopotentials (ECG, EMG, and EOG – electrooculogram) with a non-invasive, low-cost device, using dedicated sensors and other components, as well as the Arduino Mega 2560 programmable platform. Ahamed et al. (2015) also presents a portable, battery-powered, wireless, low-cost prototype designed for ECG, EMG, and EOG. In this system, an Arduino Uno is used, and an application is created to visualize and store the signals in real time, which can be further analyzed in Matlab.

3. Materials and Methods

In this laboratory, students record, visualize, and measure medical signals with Arduino sensors, as well as with the Biopac system, as will be further described.

3.1. Signals

Three 10-second signals (ECG, EMG, and PPG) are recorded successively from the same subject in the same environment using both acquisition systems, which will be further explained. Prior to the experiment, the subject signed a written consent. The electrodes and sensors are non-invasive and are placed on the skin's surface, which is cleansed with sanitary alcohol before and after each session of recording; they are placed similarly in both systems, as shown in **Figure 2**.

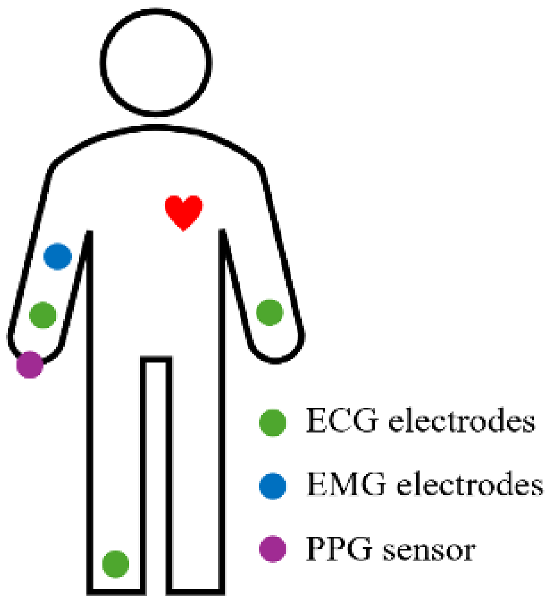

Figure 2. Electrodes and sensors placements

ECG signals. The electrocardiogram measures the electrical activity of the heart. To record ECG signals, three disposable gel electrodes are placed in Einthoven's triangle configuration: wrists and right ankle. This configuration is more practical for students to use in the laboratory and offers similar results as the chest configuration, according to the findings of Mihailovschi et al. (2023). During the recording, the subject stays still and relaxed.

EMG signals. The electromyogram measures the electrical activity of a muscle. The Arduino EMG sensor measures surface EMGs (sEMG) using a three-nondisposable-electrode-integrated plate placed on the forearm. The Biopac module also measures sEMGs using three disposable gel electrodes placed on the forearm, recording the same group of muscles. During the recording, the subject follows the sequence: 2-second relaxation, 2-second contraction (fist contracted), 2-second relaxation, 2-second contraction (fist contracted), 2-second relaxation.

PPG signals. The photoplethysmogram measures changes in blood volume in the microvascular bed of the skin (in this case, on the index finger). Both Arduino and Biopac PPG sensors use an optical method, with an IR LED (infrared light) emitting light and a photodetector detecting the amount of light absorbed or reflected by the blood. During the recording, the subject stays relaxed, with his finger placed still on the sensors.

3.2. Acquisition and Processing Systems

The goal of the proposed laboratory is to record, visualize, and measure medical signals with Arduino sensors during the Arduino classes. To confirm the accuracy of these signals, an advanced medical signal acquisition system – Biopac, is used to compare the results visually and numerically.

3.2.1. Arduino

To record signals using Arduino, a few hardware and software resources are required. **Table 1** summarizes all of them, including their roles. Some of the modules, such as ECG and EMG, were tested in our previous studies (Zîrnă et al., 2024). For this application, the Arduino UNO board is chosen because it has enough pins and memory, being also the most commonly used model of the Arduino boards and the one utilized in these laboratories. The code is developed in the dedicated Arduino IDE software, and the signals are then recorded using Excel's Data Streamer Toolbox. Due to the board's baud rate and the loss from the recording software, the signals are sampled at 200 Hz for ECG and EMG and 50 Hz for PPG.

Resource	Component	Role
Hardware	AD8232	records ECG signals
	SEN0240	records EMG signals
	GY-MAX30102	records PPG signals
	Arduino UNO	the main board that enables analog reading of the signals
	USB cable	ensures the connection between the PC and the board (powers it and allows programming it in the dedicated software)
	Jumper wires	connects the modules to the board
Software	Arduino IDE	dedicated software for developing the code for reading the signals
	Data Streamer	Excel toolbox that allows real-time data reading and storing

Table 1. Hardware and software resources - Arduino

Each module is connected to the Arduino UNO board, as indicated in **Table 2**. For a better understanding, **Figure 3** illustrates the electrical circuit of the proposed method. Even though the signals are recorded separately, the scheme displays all three modules together: AD8232 (Analog Devices, 2012), SEN0240 (DFRobot & OYMotion, 2017), and GY-MAX30102 (breakout board based on the Maxim Integrated (2018) sensor chip).

Module	**Module Pin**	**Arduino UNO Pin**
ECG	GND	GND
	3.3V	3.3V
	OUTPUT	any analog pin (A0-A5)
EMG	-	GND
	+	5V
	V	any analog pin (A0-A5)
PPG	VIN	5V
	GND	GND
	SCL	A5
	SDA	A4
the other pins are not connected		

Table 2. Arduino sensors connections

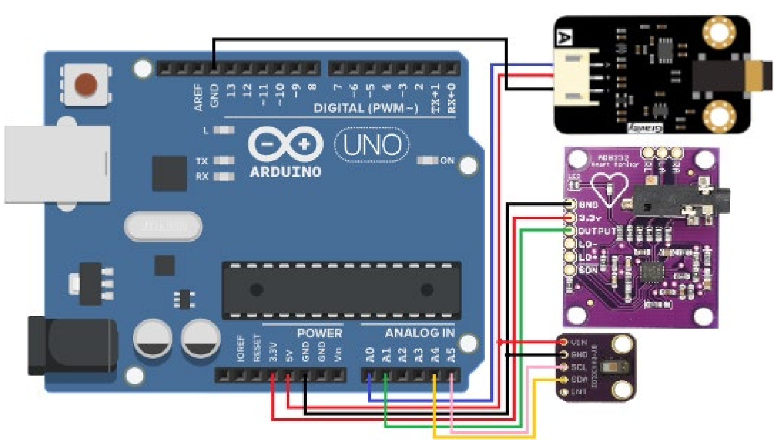

Figure 3. The electrical circuit of the proposed method

3.2.2. Biopac

The Biopac system is a professional medical signal recording equipment that includes a main unit (BIOPAC Systems Inc., 2025a) and various auxiliary modules depending on the type of recording desired: ECG, EMG, and PPG (BIOPAC Systems Inc., 2025b). Even though the signals are recorded separately, the scheme displays all three modules together (**Figure 4**). The signals are directly displayed and recorded using AcqKnowledge, the dedicated software. All three signals are recorded at 2000 Hz. **Table 3** presents all these resources and their roles.

Resource	Module	Role
Hardware	MP160	Main unit for receiving and transmitting data
	ECG2-R	records ECG signals
	DYNEM-R	records EMG signals
	PPGED-R	records PPG signals
Software	AcqKnowledge	dedicated software for visualizing, analyzing and recording signals

Table 3. Hardware and software resources - Biopac

Figure 4. Biopac system: main unit and the signal acquisition modules

3.2.3. Matlab

Even though each signal can be visualized when recorded in the software interface (Arduino IDE or Data Streamer for Arduino and AcqKnowledge for Biopac), for a simultaneous visualization and comparison, another signal processing software, Matlab, which students are familiar with, is used. Since Data Streamer stores signals in *.csv* format and AcqKnowledge supports a variety of file formats (*.csv, .mat*, etc.), the recorded signals are easy to be uploaded and read in Matlab. Different computations and graphs are then conducted to allow for visual and numerical comparisons of data from both acquisition methods, as will be further described.

4. Results

The signals are initially visualized in the program where they are recorded. The Data Streamer records the values printed on the Serial Monitor in the Arduino IDE and displays the results in real time (**Figure 5.A**). The AcqKnowledge program supports real-time signal display and recording, as well as various signal processing and analysis features, such as automatic HR computation when two R-R intervals are selected (**Figure 5.B**).

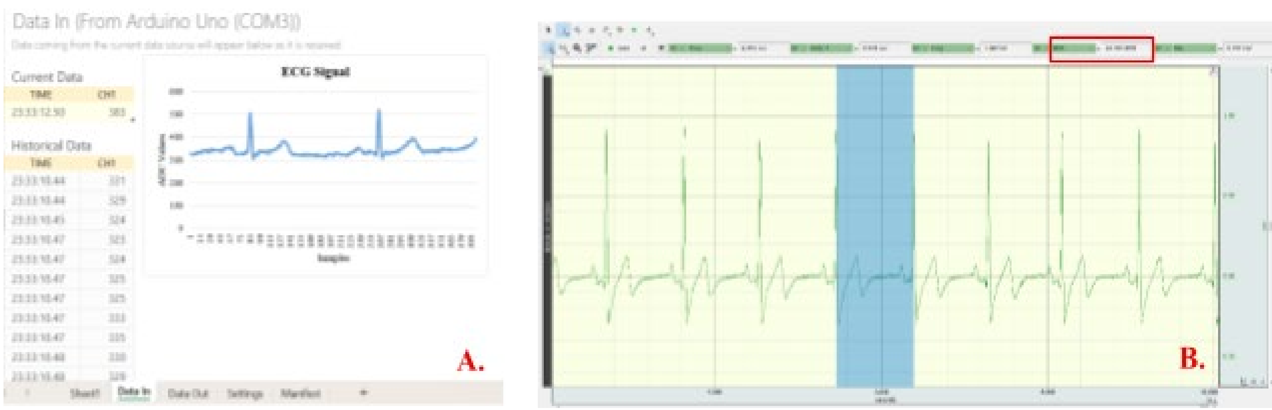

Figure 5. The acquisition interfaces during the recordings:
A. Data Streamer for Arduino; B. Acqknowledge for Biopac

After the signals are uploaded and read in Matlab, they are normalized and displayed in the same window for a general overview of the results, with no additional processing. The morphology of the waves is similar, as shown in **Figure 6**. The main difference comes from the human factor, as two biosignals cannot be identical. Furthermore, the sampling rate is significantly different, and the Arduino signals are noisier. However, the results of the applications that are further described are unaffected by these factors.

The following computations can also be done automatically in the Arduino IDE software (by coding) and in AcqKnowledge (by applying different functions), but all computations are performed offline in Matlab to allow for simultaneous signal analysis.

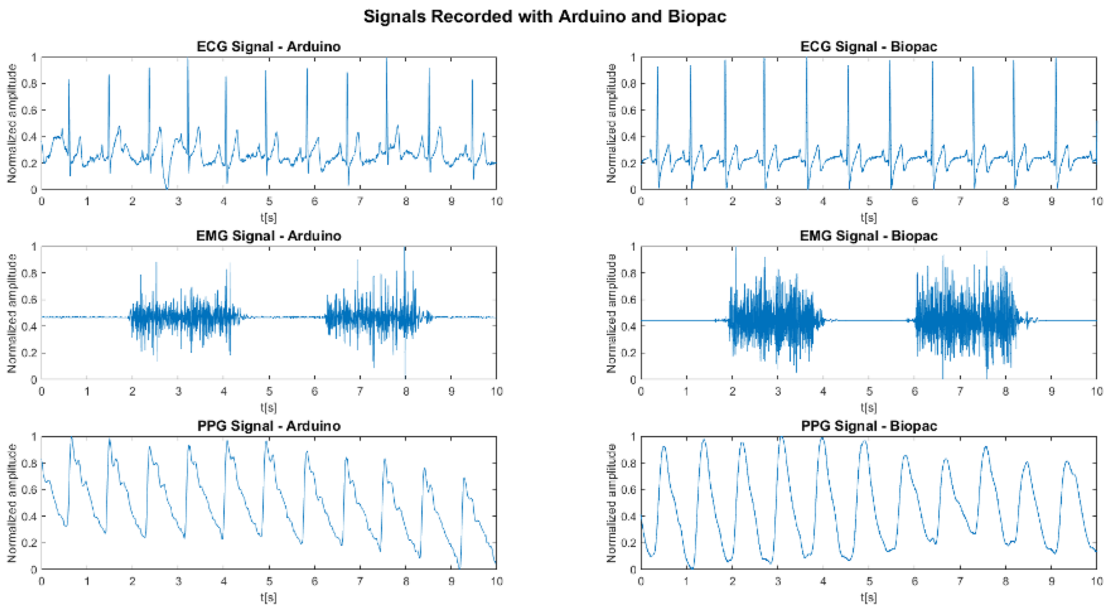

Figure 6. Signals recorded with both systems – Matlab graphs

A vital parameter that can be computed from an ECG or PPG signal is heart rate (HR), which ranges between 60 and 100 beats per minute (bpm) for a healthy individual. Values outside of this range may indicate various disorders, such as bradycardia (values below 60 bpm) or tachycardia (values above 100 bpm). Since ECG and PPG signals are correlated, they should indicate the same HR for an individual. However, the signals are not recorded simultaneously; thus, the values may slightly differ.

The algorithm used for computing HR from ECG signals (Zîrnă et al., 2025) is:

- Identify the R-peaks as local maximas within a time window
- Compute the R-R intervals' durations based on the R-peaks' locations
- Check that R-R intervals' durations are within the proper range (a regular R-R interval has between 0.6 – 1 seconds and the subject is healthy)

- Compute the average R-R interval's duration (noted as $\overline{R - R\ interval}$ [s])
- Compute the HR: $HR = \frac{60}{\overline{R - R\ interval}}\ bpm\ (1)$.

The same steps are followed to compute HR from PPG signals but, instead of identifying the R-peaks, systolic peaks are identified (which are also the highest peaks of the signal).

Figure 7 presents the four recordings, the identified and marked peaks (red triangles) and the computed HR. As can be seen, the values are almost identical, the difference coming from the fact that they are not recorded simultaneously and different electrodes or sensors are used.

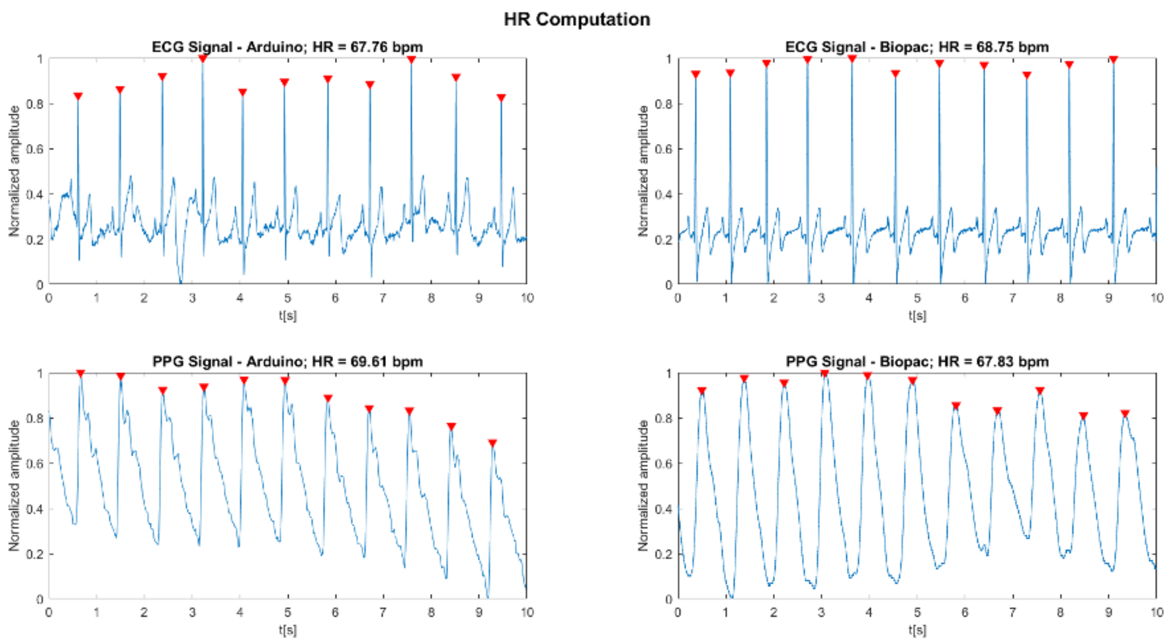

Figure 7. HR computation from ECG and PPG signals – Matlab graphs

Depending on the application, EMG signals are frequently rectified, as this converts the signals from bidirectional to unidirectional, allowing the signals to be directly correlated with the intensity of muscular force. As a result, important parameters such as global amplitude or root mean square (RMS) can be calculated. The two rectified overlapped signals are presented in

Figure 8, demonstrating that they have similar morphologies and that contractions can be easily identified and differentiated from relaxation states.

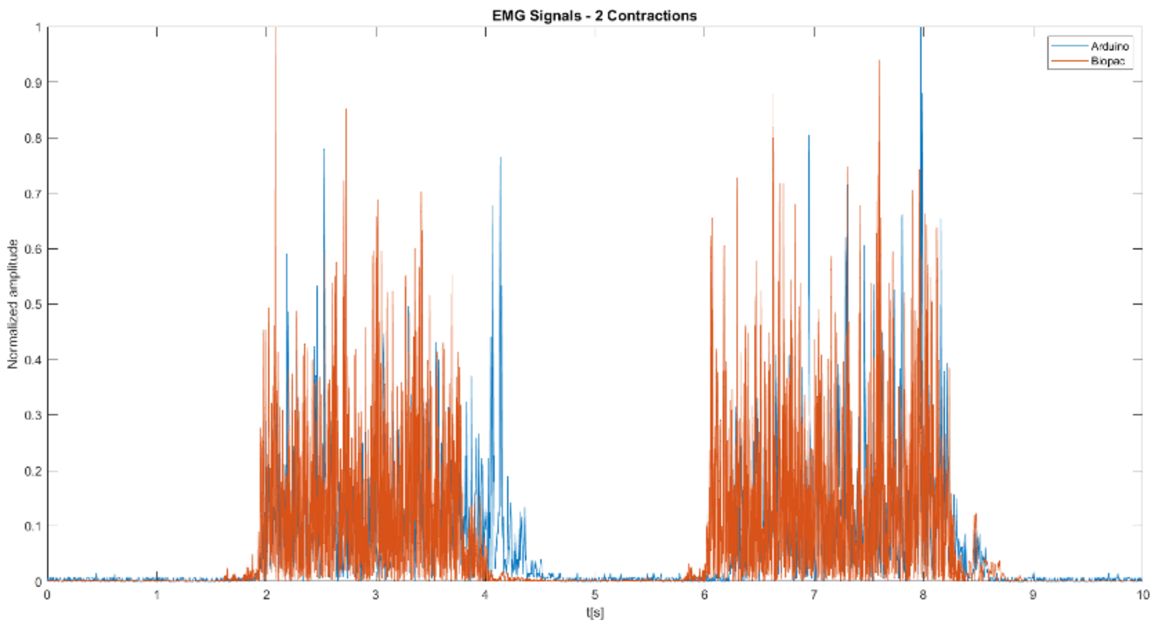

Figure 8. Rectified EMG signals: contraction vs. relaxation states – Matlab graphs

5. Conclusions

The suggested laboratory's purpose is to demonstrate another application of the Arduino in the medical field, specifically signal acquisition. To ensure that the results are valid and that these modules may be further integrated into wearable devices, the signals are compared to those recorded using a professional system known as Biopac, using the same electrode placement and acquisition protocol. As previously proved, the results are nearly comparable, suggesting that these modules are excellent for integration in wearable devices.

Students may further develop their bachelor's thesis projects by adding necessary processing steps and additional features such as alerts or displays. The use of non-invasive signal recording methods allows these projects to be easily integrated into a wide range of applications. Furthermore, Arduino is compatible with numerous processing software, such as Matlab or Python, which means that data may be easily transmitted to or received by these programs, allowing for the development of various graphical interfaces, command and control applications, and advanced processing algorithms. Data can also be wirelessly transmitted, and printed circuit boards (PCBs) can be developed to produce customized wearable devices. However, a few more components are necessary for the development of a wearable device, including wireless data transfer and autonomy, as well as the device's lightweight and comfortable wearability, which should be taken into consideration.

This approach proves that, for basic applications like monitoring vital parameters or counting contractions, Arduino-recorded signals are as useful as those recorded with professional devices. As a result, these sensors can be integrated into wearable devices for daily monitoring, fitness gadgets, e-health, and other applications. A future goal is to create a full-semester or one-year laboratory of signal acquisition and processing in which students progress from basic sensor use and simple signal processing to the development of fully integrated wearable medical devices. This allows them to combine their hardware and software skills to develop a variety of gadgets.

Ethical Approval

This study was approved by the Ethics Committee of the National University of Science and Technology POLITEHNICA Bucharest (Approval No. 25/06.10.2025). The subject provided written informed consent prior to their participation in this study.

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