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Portable Multi-parameter Patient Simulator

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Abstract:- *Finding volunteer patients and/or getting ethical approval for experimental studies on human participants are generally serious problems in the field of biomedical engineering. Therefore, this study presents a new, low cost, portable microcontroller-based multi-parameter patient simulator that makes the calibration more convenient without oscilloscope, programmable amplifier, programmable filter and stabilized voltage supply. The developed simulator generates graphical representations of three normal physiological signals these are electrocardiograph (ECG), phonocardiograph (PCG), carotid pulse (CP). Discrete wavelet transform has been used to pre-process the mentioned signals, in order to denoise and decompose these ECG, PCG and CP signals to the third approximated level. The developed multi-parameter simulator was implemented using the Arduino Due and Uno microcontrollers. The simulated ECG, PCG and CP signals are nearly equal to the real heart signals. Therefore, they are accepted to represent different scenarios of the heart sounds clinically. Graphical microcontroller-based graphical representation of ECG, PCG, CP signals and acoustical PCG wave simulator has been successfully developed to support biomedical engineering education and research studies in the field of physiological signals analysis.*

Keywords: *electrocardiograms; phonocardiograms ;carotid pulses; GUI; simulator.*

1. INTRODUCTION

In biomedical engineering, creating and testing medical devices needs accurate and dependable ways to mimic physiological signals. Patient simulators are very important for calibrating and validating medical devices like blood pressure monitors, electrocardiographs (ECG), and phonocardiographs (PCG) [1]. They do this without needing human volunteers or complicated ethical permissions. These simulators create fake physiological signals that are similar to real human situations. This lets researchers, teachers, and doctors test how well a gadget works, train medical staff, and do research investigations [2]. A lot of the multi-parameter patient simulators that you can buy are expensive and don't always have the ability to make a lot of different physiological signals with great realism. Also, in places like Iraq, using medical equipment from other countries is hard because it is expensive and there aren't many people who know how to calibrate and maintain it.

This studyproposes an innovative, economical, and portable multi-parameter patient simulator aimed at tackling these issues. The suggested system uses microcontroller technology, notably the Arduino Due and Uno platforms, to make accurate copies of ECG, PCG, and carotid pulse (CP) data. The system is made to be easy to use, cheap, and flexible enough to be used in both educational and clinical settings, especially when resources are limited. Adding a Nextion screen and an MP3 shield to the system to create a graphical user interface (GUI) improves its functionality and makes it a useful tool for biomedical engineering education and equipment calibration. This project aims to help

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Iraq's medical technology industry by making simulators that are cheaper than foreign ones but work just as well as high-end gadgets.

2. Related Works

Research on making patient simulators for biomedical uses has been going on for a long time. Many studies have focused on making devices that can simulate physiological signals that are both cheap and portable. Below is a summary of several important related papers that help explain the idea behind the proposed portable multi-parameter patient simulator.

Smith et al. created an interactive tool to simulate ECG waveforms, concentrating on the formation of the QRST complex, which signifies ventricular depolarization. Their numerical modeling technique calculated ECG signals on the thorax, establishing a basis for comprehending cardiac electrical activity. This work stressed the need for precise waveform generation for training and testing, but it didn't talk about multi-parameter simulation or portability, which are very important for real-world use in places with few resources [3]. Moreover, researchers investigated electronic devices for ECG simulation designed for the training of medical professionals and the evaluation of automated ECG machines. Their work demonstrated the utility of simulators in educational settings and device validation. However, their systems were limited to single-parameter (ECG) simulation and required external calibration equipment, which contrasts with the proposed multi-parameter approach that integrates ECG, PCG, and CP signal generation in a single portable device [4, 5].

Furthermore, studies have examined the simulation of ECG signals to analyze aberrant cardiac impulse propagation. Their work highlighted the need for simulators to replicate a variety of pathological conditions for diagnostic training. Their approach offered significant insights into ECG simulation; nevertheless, it omitted important physiological signals such as PCG and CP, which are crucial for thorough medical device testing [6]. Add to that Mohamed et al. developed a microcontroller-based simulator for graphical heart sound simulation, including conditions such as mitral valve insufficiency, aortic stenosis, and ventricular septal defects using the Arduino Due platform. This work is quite similar to the proposed idea because it used the same microcontroller technology to make heart sounds (PCG). The system was only able to simulate PCG and did not include ECG or CP signals, which made it less flexible than the multi-parameter simulator suggested in this work [7].

Li Nuo et al. created a calibration tool for multi-parameter simulators to help with the problem of checking how accurate the simulator is. Their work underscored the lack of specialized calibration equipment for multi-parameter systems, particularly in regions with underdeveloped medical metrology infrastructure. While their study focused on calibration standards, the proposed simulator in this project integrates signal generation and visualization, reducing the need for external calibration devices [8].

Cho et al. presented a novel ECG simulator design, emphasizing low-cost and digital signal processing techniques. Their work highlighted the potential of microcontroller-based systems for affordable medical simulation but was limited to ECG signal generation. The proposed system extends this concept by incorporating multiple physiological signals (ECG, PCG, CP) and a graphical interface for real-time visualization, enhancing its applicability in both educational and clinical settings [9].

The existing literature demonstrates significant progress in patient simulator technology, particularly in ECG simulation [10-14]. However, there remains a gap in developing affordable, portable, and multi-parameter systems that can generate and visualize ECG, PCG, and CP signals simultaneously.

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The proposed simulator addresses this gap by integrating these capabilities into a single, low-cost device, leveraging open-source hardware and advanced signal processing techniques. Furthermore, the focus on addressing local challenges in Iraq, such as reliance on imported equipment, positions this work as a significant contribution to biomedical engineering in resource-constrained environments.

3. MATERIALS AND METHODS

The structure in Figure 1 shows an overview of the main stages applied in this study to develop the multi-parameter simulator.

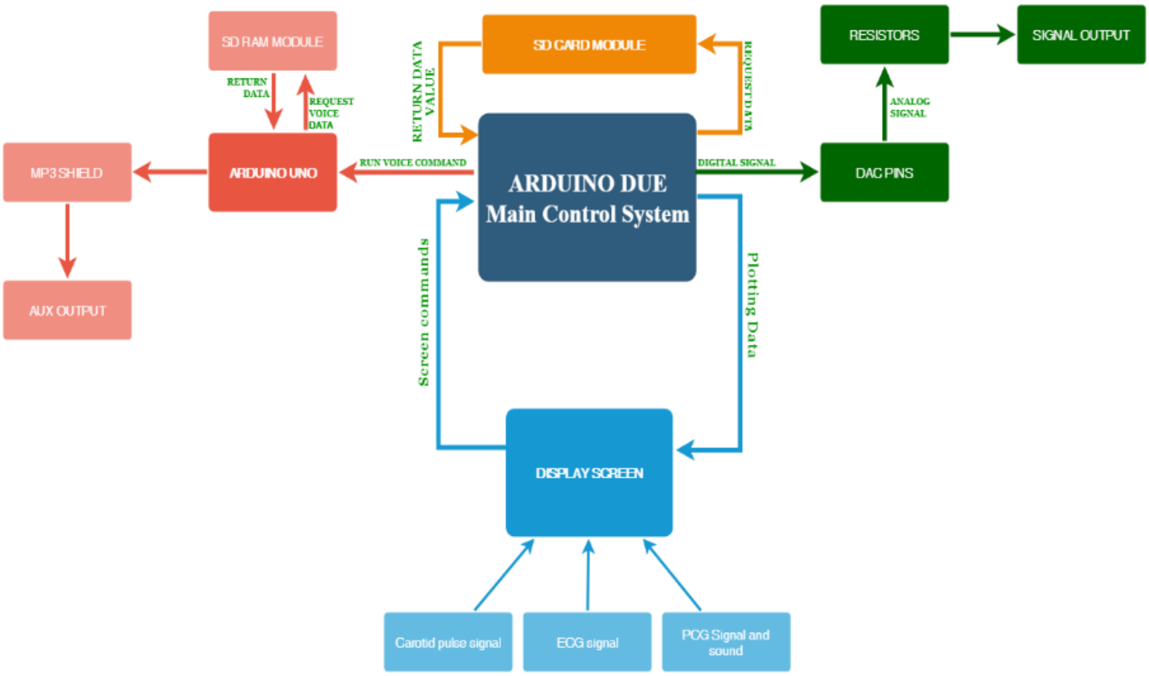

Figure 1. General Block Diagram of the proposed system

3.1. System Architecture and Components

The developed portable multi-parameter physiological signal simulator was constructed based on a microcontroller-oriented architecture, integrating essential modules for data acquisition, signal processing, and visualization. The overall schematic diagram is depicted in Figure 2, illustrating the interconnected components, including the Arduino Due microcontroller, SD card module for data storage, Nextion display for user interface and graphical output, serial interfaces for communication with an Arduino Uno and MP3 modules, and digital-to-analog converters (DACs) for signal output.

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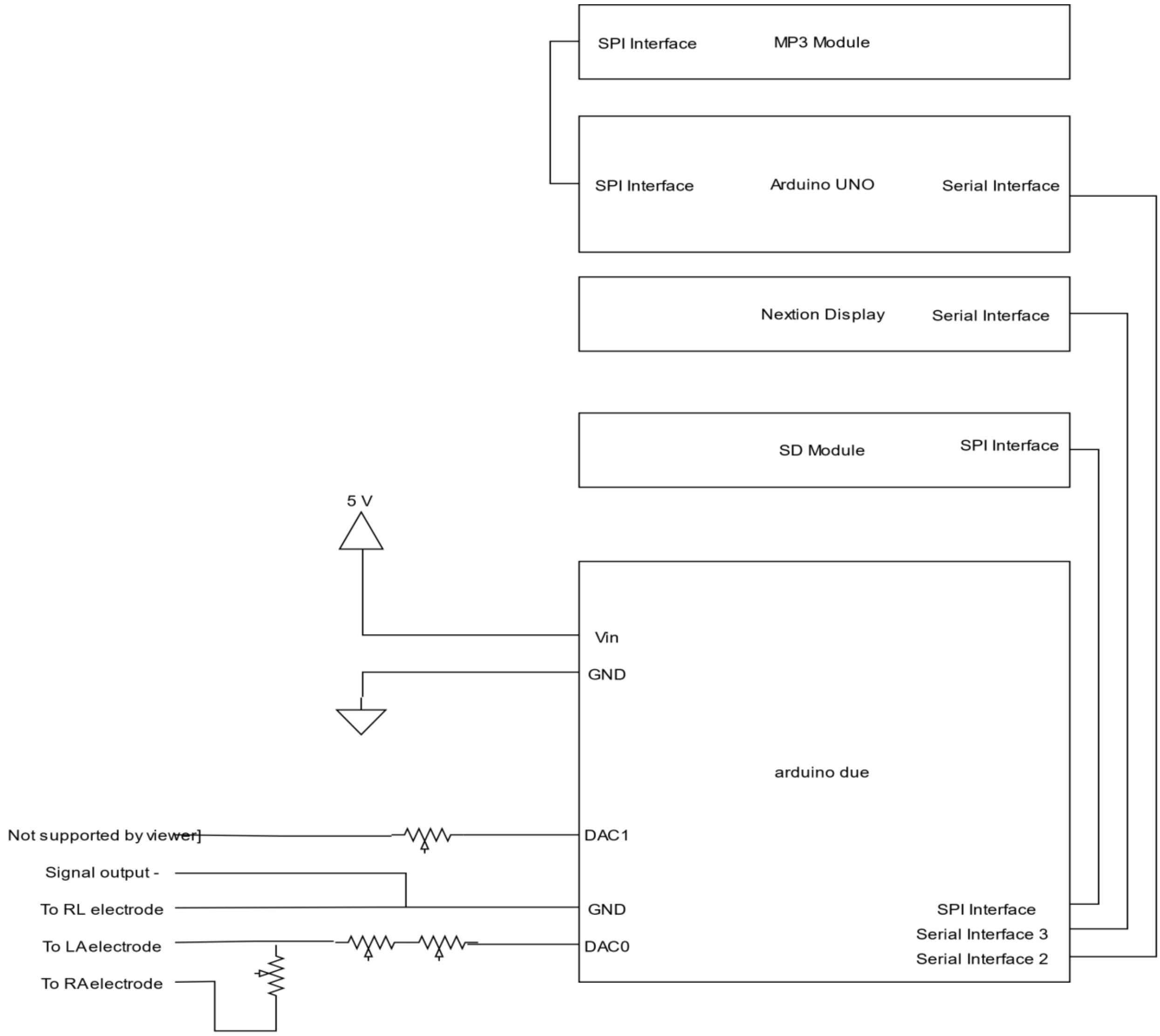

Figure 2. The schematic diagram of the device

3.2. Physiological Signals Data Acquisition

In order to simulate physiological signals, real data of these signal have been needed. Therefore, the ECG, PCG and CP were downloaded from PhysioBank.org which is the most appropriate website for physiological signal, it is a large and growing archive of well-characterized digital recordings of physiologic signals and related data for use by the biomedical research community. PhysioBank currently includes databases of multi-parameter cardiopulmonary, neural, and other biomedical signals from healthy subjects and patients with a variety of conditions with major public health implications, including sudden cardiac death, congestive heart failure, epilepsy, gait disorders, sleep apnea, and aging.

At first the data with normal rhythm ECG signal were downloaded as .dat format file these files were then decoded by special matlab algorithm that will explained in detail later. The ECG signal is one of the most difficult signals to be detected with its complex waveform and tiny amplitude. Usually, the upper limit of normal amplitude of ECG signals 3mV. In the same manner, the CP of the blood pressure was simulated to an output to be 40uV/V/mmHg or 5uV/V/mmHg [8].

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3.3. Signal Generation and Calibration

3.3.1 ECG Signal Processing

After downloading the (.dat) files that include ECG signals cases from physiobank.org website [9], these files were imported into MATLAB. A particular algorthim has been developed for importing and decoding the data into a MATLAB matrix that contain the signal data.

ECG data is the real readings from ECG device which they are values in the scale of millivolt or less. In Arduino due it has 12 bit DAC pins it means to generate an analog signal has the highest value of 3.3 volt (which it is default value in arduino due configuration), then the smallest analog value the DAC can produce is 212 = 4096 (this number represent the resolution in the analog signal), dividing 3.3 volt on 4096 the result is proximate to 805 microvolt this is the smallest step value in the analog signal at the scale of 3.3volt. ECG signal data require to be within amplitude no more than 4096 and no less than 0. The scales of ECG signals have been changed to be between 0 to 4096. The function that has been used were programmed in matlab to perform this operation automatically. The new matrix was containing values ranged from 1 to 4096 with a sampling frequency of Fs=250 sample per (Hz).

After looking for the ECG data from physiobank.org [9] and importing them into matlab, the next step was changing the Fs which was not really efficient because of the generation of this signal was implanted in timer interrupt function within the microcontroller that worked perfectly under FS = 1000 Hz (meaning that it need to run one sample every one millisecond), and the heart rate is normally 72 BPM [10].

But an option is produced that permit the user to change the heart rate between 60 to 160 BPM. in general the trick is to control the quiescent phase (of cardiac cycle) - which is The period of relaxation, from the end of the T wave to the start of the next P wave, especially the time during which the valves to the heart chambers are closed and the myocardium is relaxing (see isovolumetric relaxation) and the chambers can begin to refill. This period is changed depending on many factors from person to another [11], the problem solved by designing a PQRST signal with a constant sampling rate of 800 which this is the best interval of normal PQRST wave [12].

Then in this case it need to resample the data of ECG, a costume function that made in matllab which change the sample rate automatically of matrix. The result is as shown in Figure 3. Now the signal data is complete and ready to be copied to SD ram as txt file.

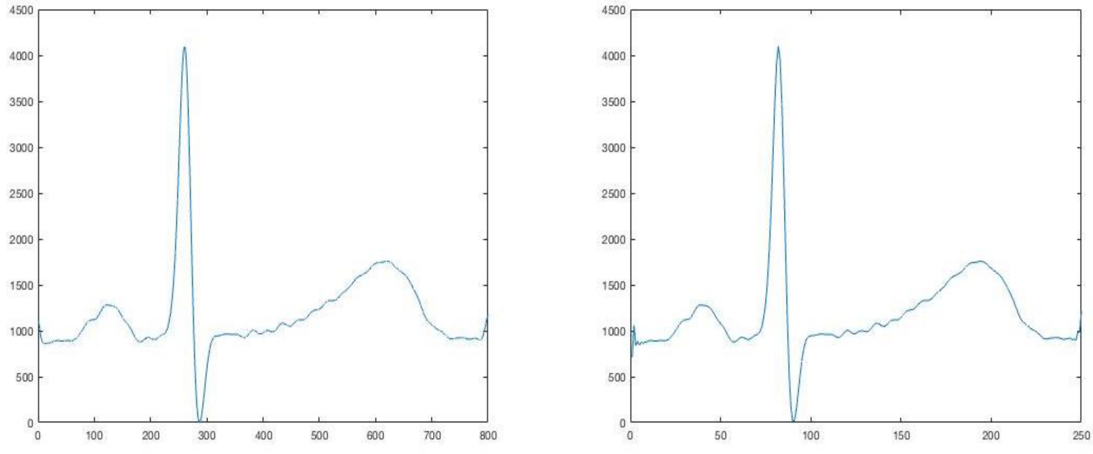

Figure 3. The resample of ECG signal

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3.3.2 PCG Signal Processing

PCG signal is acquired from decoding heart sound files recorded by using digital stethoscope, the flowing figure show the decoding result and signal component

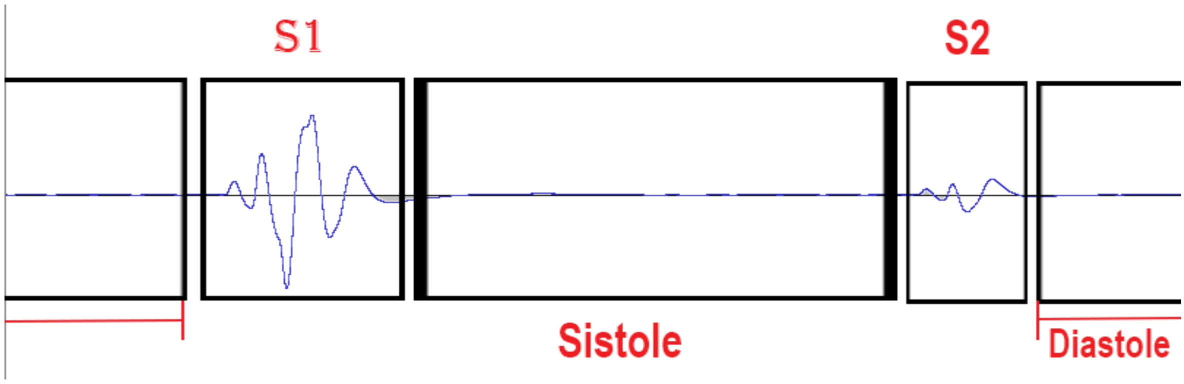

Figure 4. The PCG signal

The procedure is done by using one of sound decoding application, then zooming the scale of signal to see close and clear of signal components, as shown above. The sound that is collected in a PCG is given by the vibration that the heart performs during its cardiac cycle. This vibration is what produces the acoustic wave that is propagated through the chest wall. The heart rate is the main component of the acoustic wave, but also each part of the heart itself has a particular constitution with its own biomechanical characteristics: natural frequencies, elasticity, damping and mechanical and acoustic impedances. This means that both the vibration of the heart and the acoustic wave it produces, cover a wide spectrum of frequencies, which can range from 1 Hz or less, to over 1500 Hz. The amplitude of the acoustic signal is around 80 dB. In the auscultation of the normal heart we mainly discover two noises: the S1 ("dumb"), which is a wide vibration that is due to the movement of the blood during the ventricular systole, to the closing of the mitral and tricuspid valves and to the posterior opening of the pulmonary and aortic valves; and S2 ("tub") that is due to the deceleration and reverse flow of blood in the aorta and pulmonary artery, by closure of the aorta and pulmonary arteries and opening of the tricuspid and mitral arteries. This sound is shorter and more acute, and coincides with the end of the T wave.

3.3.3 CP Signal Processing

Same procedure taken on ECG signal is made on CP signal and the final result is shown in Figure 5. This signal has same sample frequency and amplitude as ECG but in term of generating this signal with actual values the potentiometer resistors will be adjusted to lower the amplitudes to reach proximate values when compared to original signal.

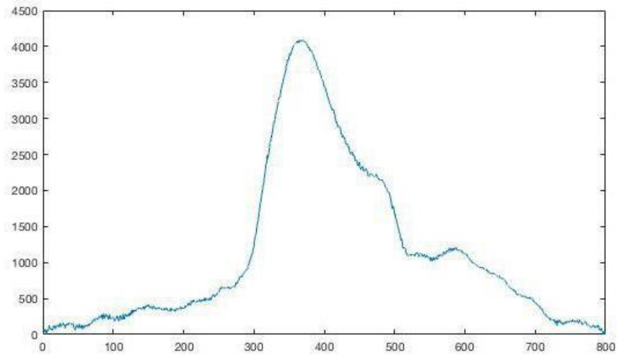

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Figure 5. CP signal

3.3.4 CODING ARDUINO DUE

After connecting the device as shown in Figure 6, now it was the time for coding the study. The system code basically consist of 2 part. Firstly, coding the Arduino Due to control all system and secondly coding the Arduino Uno to receive commands from due and run the sounds.

Thus, before begin the code we need to design the flowchart that Arduino will work in. as shown in Figure 6, the Arduino due microcontroller has needed to do multi-function at the same time which are check if there is any commands came from nextion screen and read this commands and send signal plotting data to screen when the user hit start, buffer the signal data to DAC when the user hit start, the coding flow chart is shown as in Figure 6.

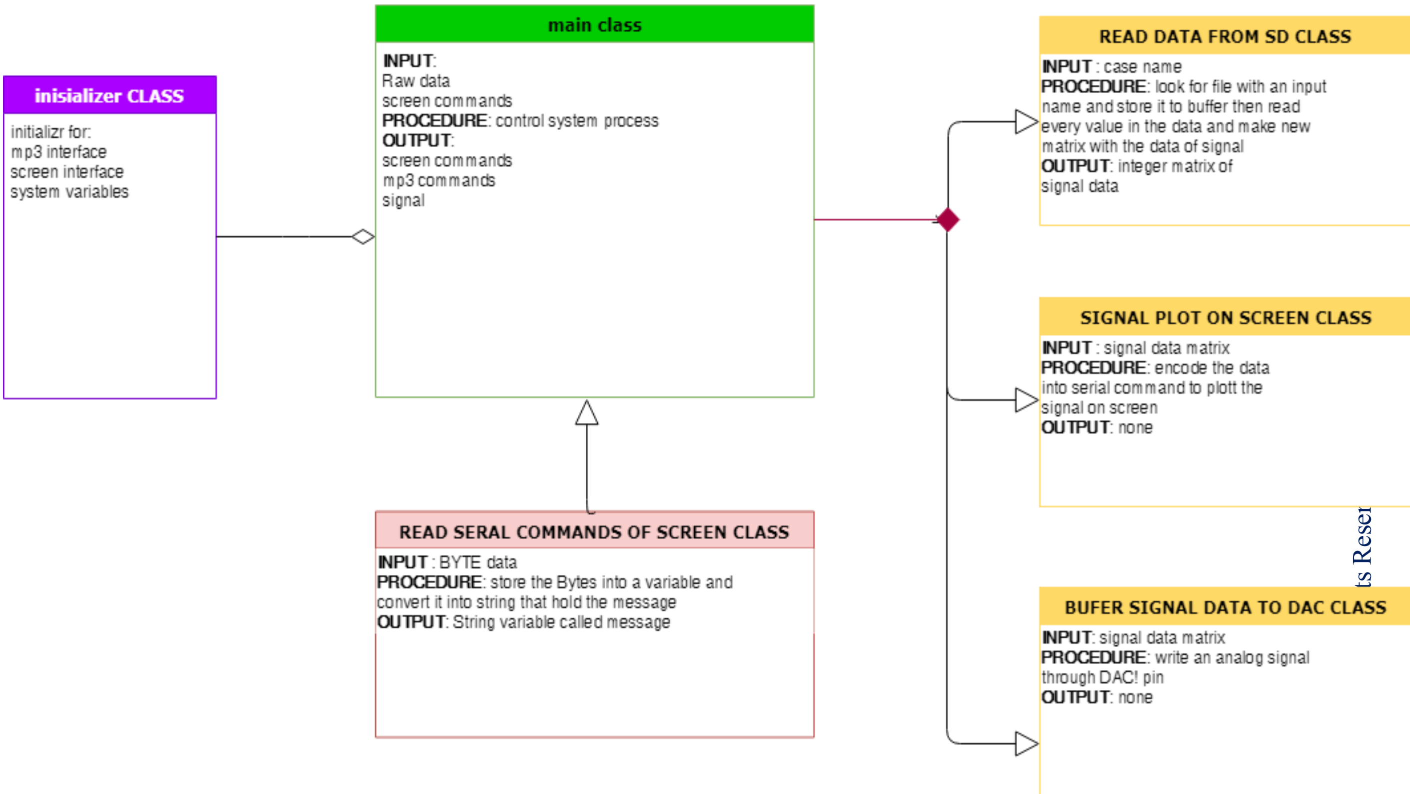

Figure 6. Flowchart of Arduino due code

First the initializer include the timer library and spi library also open serial interface with Arduino Uno and screen, main class has the most arithmetic operation of the code it identify the message came from screen and make a diction based on it which either case selection or start this case. The input for main fuction is the command reader class this class is always listen to the serial (of screen) and pick up any data came from it, the data come in byte mode to fist it need to collect all the bytes in one matrix variable and then convert this variable into string object to easily deliver it to main function, the output class is 3 one for continuous writing data to DAC and to screen and other is for reading the files related to specified selection.

3.3.5 Coding the Arduino UNO

Arduino Uno is connected serially with Arduino due and it has the main class that continuously listen to serial bytes cam from Arduino due and make dissection based on incoming commands the coding flow chart is summarized as shown in Figure 7.

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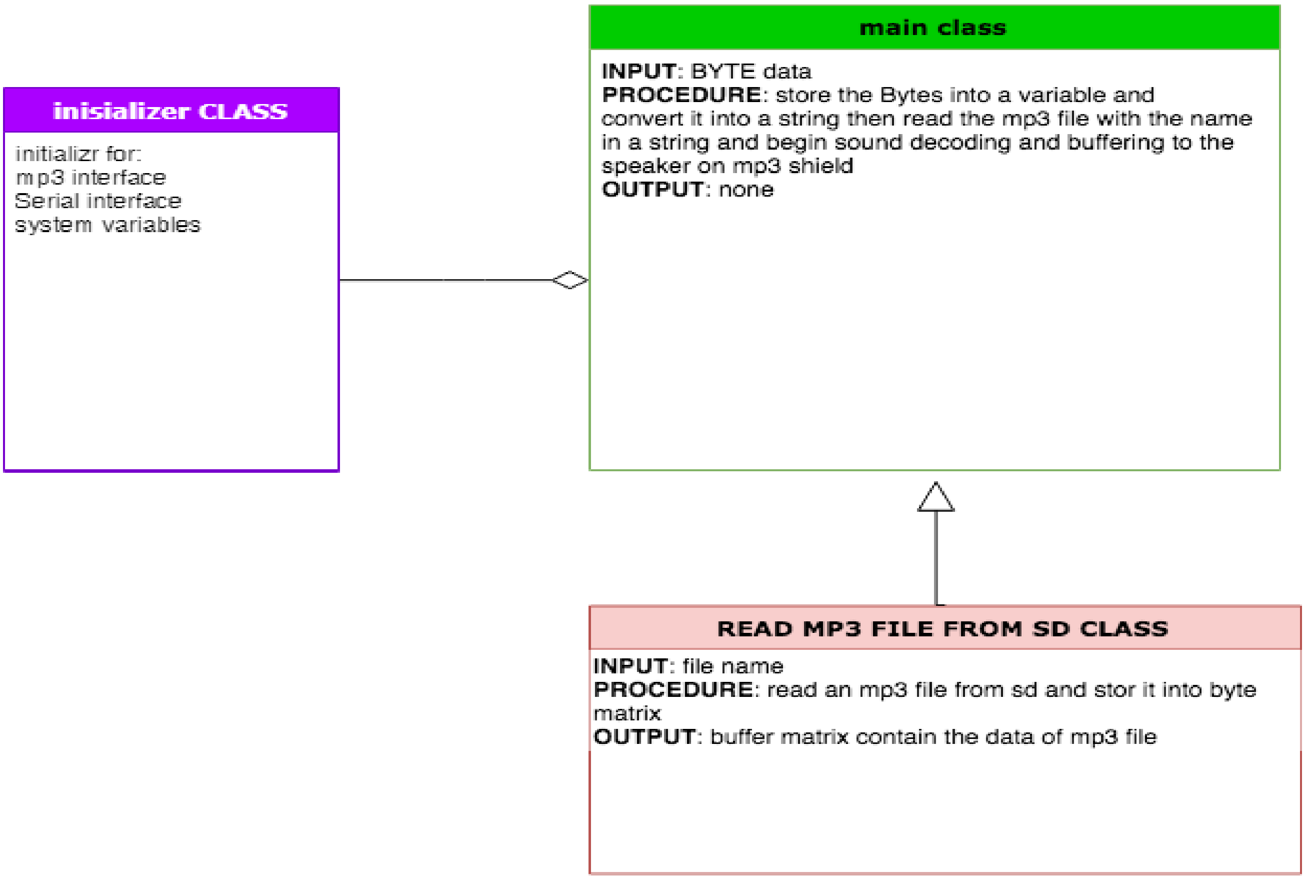

Figure 7. Flowchart of Arduino Uno code

As shown in Figure 7, the code begin with initializer that prepare the serial interface with Arduino due and begin and test spi protocol with SD module, also initialize the library of mp3 controller shield, the main class is continuously listen to the serial and read any bytes come from it and store it into byte matrix and convert the byte matrix into string according to ASSCI code standards and then pass the string into file read class which then call the reading file function and store the incoming file data into buffer matrix (100 sample at a time) then call the function of running the mp3 file through the speaker mounted on the shield.

3.3.6. Design the Box

The box was made by cutting the plates with CNC machine, the plates used made from alucobond as the demention shown below, then the plates is connected togather using strong adhesive glue as shown in Figure 8.

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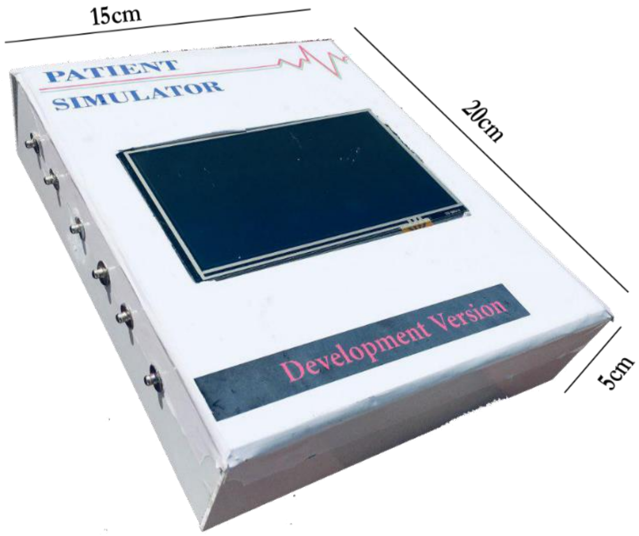

Figure 8. Device layout

4. RESULTS AND DISCUSSION

In this work a portable low cost patient simulator using a new microcontroller based ECG, PCG and CP signals has been developed. This simulator has been adapted to generate a graphical representations of ECG, PCG and CP with the graphical acoustic of PCG signals for the normal cases. All these results are promising, therefore, this study is being essential to support the biomedical engineering education and research studies in the field of physiological signals analysis.

4.1. ECG Signal Visualization on Screen

The screen has resolution of 840 x 460 pixels. And the waveform window has approximate of 255×700 pixels as shown in Figure 9.

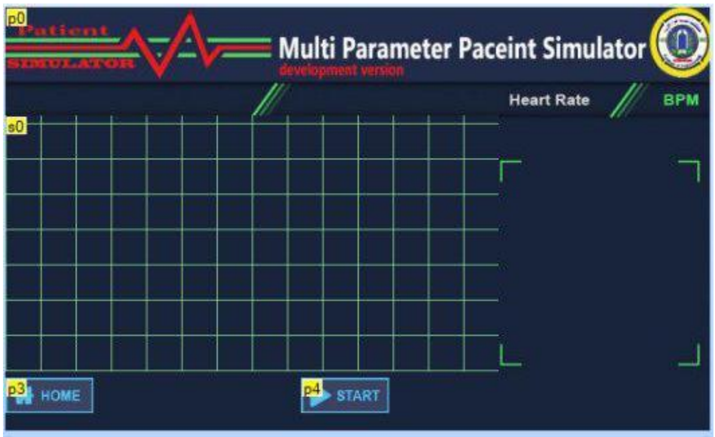

Figure 9. The signal visualizer GUI design

So that require to virtually modify the signal data to fit in this scale and this is the function of Arduino due as explained previously. after modification the signal is plotted in screen as shown in Figure 10.

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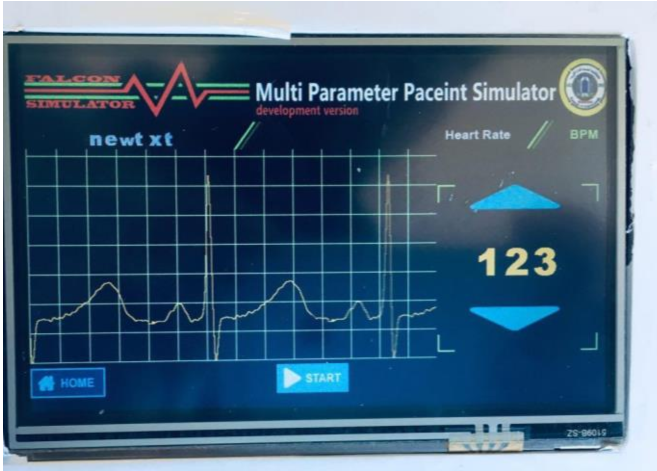

Figure 10. Plotting of ECG signal on screen

4.2. PCG Acoustic Signal

After adding the heart sound of some cases as listed in the Figure 11.

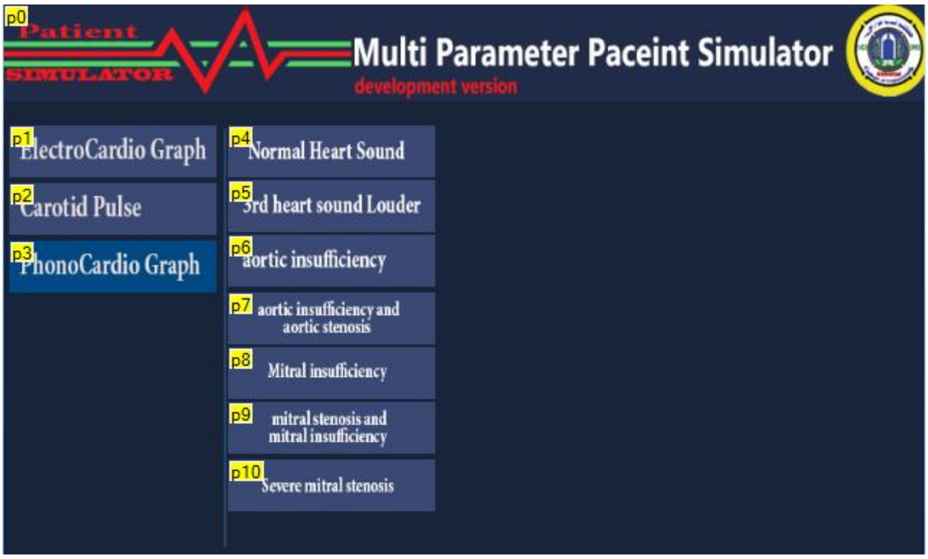

Figure 11. PCG heart sound GUI design

The system will tend to run the sound that corresponding to the choice of user through AUX that can be connected with headphone or speaker.

4.3. PCG Signal Visualization

To generate PCG signal that can be seen throw oscilloscope require to facilitate audio generation through DAC pins of Arduino mega, same audio file that used in mp3 module is saved in SD card that connected to Arduino due then importing this file and begin to run the file, monitoring PCG signal require that oscilloscope probes to connected between DAC pin and ground pin the result is shown in Figure 12.

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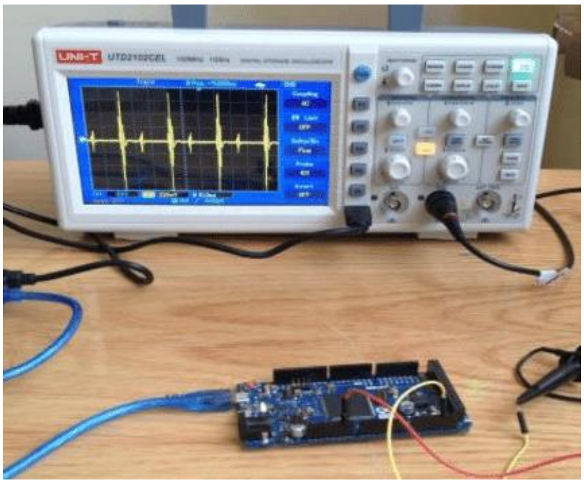

Figure 12. The PCG visulationon oscilloscope

Where the high peak is S1 period fallowed by systole period then the small peaks is S2 period and finally the last period is diastole periods. The voltage ranges of this analog signal is also between 0-3.3 volt.

4.4. CP Signal Visualization

As mentioned before CP signal is encoded in data file then it used to implement analoge signal over DAC pin after importing these data from SD card and stored in Arduino due RAM the final result is shown in oscilloscope in Figure 13.

Figure 13. the CP visualization on oscilloscope

5. Conclusion

A portable, low-cost patient simulator has been created for this research. It uses a new microcontroller-based ECG, PCG, and CP signals. This simulator has been modified to produce graphical representations of ECG, PCG, and CP, along with the graphical acoustics of PCG signals for standard cases. All of these results are encouraging, therefore this study is very important for helping biomedical engineering students and researchers learn about and study physiological signals analysis. This study has several limitations, as this project involved multi-cases imported including heart sound files from various references in attempt to reproducing these signal relative to their actual values, but the issue is in the amplitude, it is too small that could not reproduce them with basic electronics and connections, also the connectors of simulators has specific properties like it has customized shape and it made with pure metals.

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