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DESIGN OF A LOW-COST PORTABLE WIRELESS ECG DEVICE

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Abstract:

Cardiovascular diseases (CVDs) are a group of disorders of the heart and blood vessels. Some of these include coronary heart disease, cerebral vascular disease, peripheral heart disease, rheumatic heart disease, deep vein thrombosis, and pulmonary embolism. The study aimed to design a prototype of a portable low-cost ECG wireless monitoring device. In the first stage of the simulation we used a simulation software proteus to carry out the simulation. The simulation involved adding of the Arduino library of proteus into the simulation software as well as adding of the heart beat sensor. In the second stage of the simulation we used data collected from a 60 beat/minute ECG which required a wave form of 543 samples with 457 samples.

Keywords: Design, Low-Cost, Portable, Wireless, ECG Device
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Background

Cardiovascular diseases (CVDs) are a group of disorders of the heart and blood vessels. Some of these include coronary heart disease, cerebral vascular disease, peripheral heart disease, rheumatic heart disease, deep vein thrombosis, and pulmonary embolism to mention but a few [1]. Chronic diseases such as cardiovascular diseases (CVD) are major health problems in most ethnic minority and migrant populations living in high-income, low-income, and middle-income countries (LMICs) [2]. By the same token, CVD is a looming threat that is creating a double burden in most of the countries where these populations originate from. The causes of the rising burden are unclear, but they are likely to be multifaceted. Mostly for high-income countries the trace of CVD is trailed back to the nature of behavior and lifestyle management. However, globally even with sub–Saharan Africa certain risk factors have been found to account for 90% of CVDs with some of the causes being smoking, alcohol consumption, obesity, low physical activity, diabetes, high level of lipid consumption, and hypertension[3].

Cardiovascular diseases can clinically be presented in a range of asymptomatic ways e.g. (silent ischemia, angiographic evidence of coronary artery disease without symptoms, etc.). Although CVD may directly arise from different etiologies such as embolism in a patient with atrial fibrillation resulting in ischemic stroke, and rheumatic fever causing valvular heart disease. Most of these diseases refer to the main key four entities **1). Coronary artery disease** (CAD): Sometimes referred to as Coronary Heart Disease (CHD), results from decreased myocardial perfusion that causes angina, myocardial infarction (MI), and/or heart failure. It accounts for one-third to one-half of the cases of CVD. **2) Cerebrovascular disease** (CVD): Including stroke and transient ischemic attack (TIA). **3) Peripheral artery disease** (PAD): Particularly arterial disease involving the limbs that may result in claudication. **4) Aortic atherosclerosis:** Including thoracic and abdominal aneurysmsAccording to the World Health Organization (WHO) in 2005 the global statistics found an estimated 17.5 million people died of CVD representing 30% of the global deaths of which 80% were from low- and middle-income countries[3]. Further projections also showed that by 2020the mortality of CVD will greatly increase 120% for women and 137% for men. The risk factors associated with CVDs are mostly behavioral risks, which account for more than 60% of CVD deaths globally. The effects of these risk factors may show up in individuals as risk conditions, namely hypertension, diabetes, and overweight/obesity [2],[4].

But centering down to the rest of the world such as LMICs, it is observed that these countries are facing an epidemiological shift from infectious diseases to chronic diseases, such as cardiovascular diseases (CVDs). CVDs incidence in low- and middle-income countries is frequently attributed to the prevalence of hypertension, diabetes, and overweight/obesity [4].

The major health concerns have been focused on infectious diseases, nutrition, and prenatal diseases, while keeping the "unfinished agenda" of heart diseases and cardiovascular diseases to be a lesser point of focus and yet it has become one of the leading causes of death in sub–Saharan Africa with ischemic heart disease having a lead of 429 deaths per 100,000 deaths per population [5]. The emergence of the CVD epidemic in the developing countries during the past two to three decades has attracted less comment and little public health response, even within these countries. It is not widely realized that at present, the developing countries contribute a greater share to the global burden of CVD than developed countries [1]. Then considering a country like Uganda, CVDs health challenges include hypertension and coronary artery disease and are

found mostly in urban areas. Rheumatic heart disease and heart failure which are due to cardiomyopathies have proved to be a challenge in healthcare facilities and they contribute to about 17.1 death rates annually [6] [7]**.** In order to curb the above challenges, Uganda Heart institute (UHI) conducts Regional ECG workshops to equip doctors with knowledge to identify life threatening conditions such as arrhythmias and Myocardial infarction. In addition to workshops, Regional Hospitals (RRH) are supported and encouraged to make early diagnosis and referral of severe cases to UHI. Therefore, in regardance to CVDs diagnosis, prevention and treatment, CVDs are diagnosed using laboratory tests and imaging studies and also medical history [8]. The common tests used todiagnose CVDs include blood tests, stress testing, echocardiography [8] etc. CVDs prevention is associated with physical activity because according to several researchers, it has been proved to have a positive impact on CVD prevention[9],[10]. Furthermore, there are various ways of treatment of CVDs whereby the use of traditional medicinal plants has rapidly expanded recently in addition to metabolomics[9]. More to this, according to recent studies, thereare other approaches used to treat CVDs such as simple chemical component separation and drugs. The use of drugs have emerged the best forms of CVD treatment because it is obtained from Natural products such as medicine plants[11].The aim of the study was to design a prototype of a portable low-cost ECG wireless monitoring device.

METHODOLOGY.

Data collection tools.

During the study, we used both qualitative and quantitative data collection methods. Qualitative data were collected using interviews filled by ourselves by face-to-face interactions and quantitative data will be obtained from questionnaires which were filled by patients with cardiovascular diseases at Mbarara Heart Centre.

Sampling techniques.

Purposive sampling, stratified random sampling, and simple random sampling were used to identify key respondents, select health facilities, and divide the population into small groups respectively.

Sample size and sample location selection.

We used random sampling where we selected Mbarara Heart Centre. In using this kind of sampling. We used statistical formulas to determine the sample size because we may not afford handling a big population.

Sample size=z^2 * p (1-p)] / e^2

Z- Z score

E- Margin of error

P-standard of deviation.

We identified 9 respondents from Mbarara heart center using Microsoft word tables.

Table 1: showing the sample selection and sample size using the sampling techniques

No	Category	N	S	Sampling technique
1	Cardiologists	5	1	Purposive sampling
2	Nurses	20	8	Random sampling
3	Patients	50	9	Random sampling.

Key: N-population size S- sample size. No- Number. Interviews

We designed an interview guide which were used to interview cardiologists and Nurse who were the key respondents of the study. We posed questions intended to lead the respondents to provide data to meet our specific objective one and probe them to provide clarification about the responses provided.

A structured interview guide was used to stimulate them into a detailed discussion of challenges associated with the existing ways of diagnosing and managing CVDs and how we are proposing to design a low-cost portable ECG device so that they provide can provide guidelines on how we should design it to make diagnosis and accessibility of ECG devices easy.

Interview questions.

1) How many patients do you attend annually?
2) What are the common CVDs, patients normally report with?
3) What could be the causes of the CVDs that they report with?
4) What are the age brackets of patients that report with CVDs and estimate the number ineach age bracket?

5) What are some of the equipment you use for diagnosis?
6) What's the cost and are they really affordable?
7) How big are they?
8) Would you wish to have remote monitoring of patients and what type of equipmentwould you wish to have?
9) After diagnosis, how do you constantly post manage the patients?
10) What is the cost of maintenance for the available ECGs and purchase?

Microsoft excel sheets. Was later analyzed using graphical interpretations.

Specific objective two.

In order achieve the design of a low cost portable ECG device, we tried to come up with simulation designs to mimic the desired results for the physical prototype. This is because we did not obtain the materials to build the ECG device.

Data analysis and design.

The data obtained was presented in the tabular form using

equirement	**Specifications**	**Description of the component.**
Microprocessor	Arduino UNO	This is purposed for data acquisition from the ECGmodule.
ECG module	AD83232	This is an integrated signal conditioner block for ECG and other bio-potential applications. It extracts, amplifies and filters small signals from the heart.
ECG electrodes	Disposable	These are attached on the patient's body using sticky pads
Bread board		
Power supply	5V-9V supply	This is used for powering up the ECG system.
Connecting wires	Female and male jumper wires	Used for connecting components on the breadboard.
Bluetooth module	HC-06	This is used to increase flexibility in the device by displaying the results on phone from the microcontroller.
Software requirements		
Arduino IDERR		This is a compilation environment for the code that runsthe system.

Requirement specification for the design of ECG device.

The first project milestone was to think critically how to come up with a low cost portable wireless ECG device for real time monitoring of CVDS. A list of requirements with theirspecification was drafted before the design process was started.
Due to the outbreak of COVID 19 pandemic, we delayed to access the project requirements, however we have decided to come up with different simulations to mimic the design of portable low-cost ECG device which based on Arduino UNO as we wait for the components.

Project design.

The project was divided into two stages:

Stage 1: Heart rate simulation

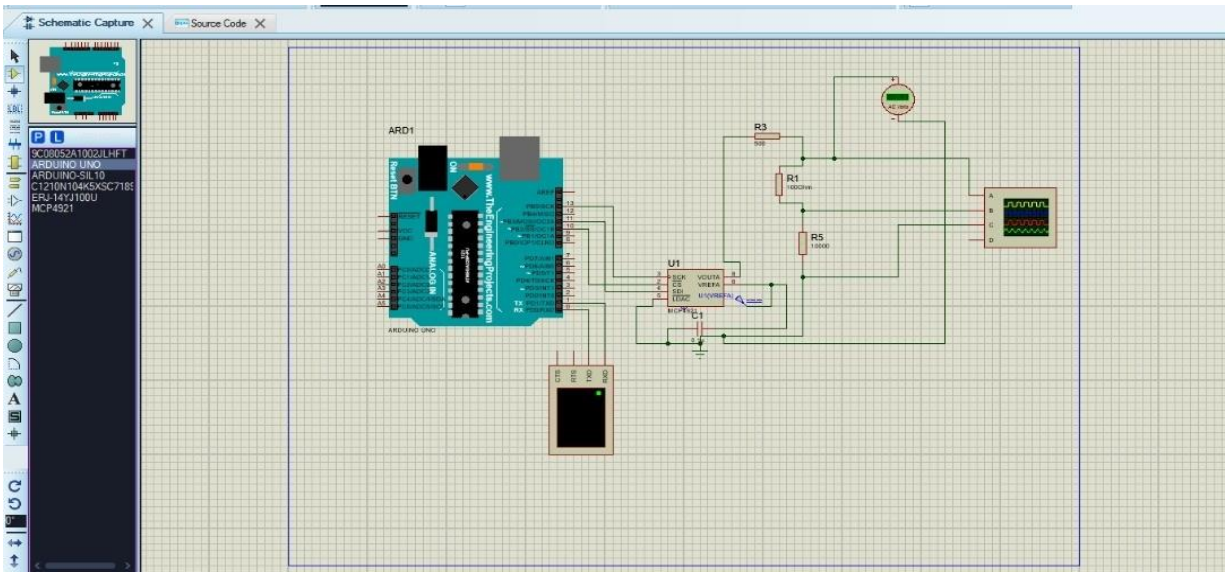
In the first stage of the simulation we used a simulation software proteus to carry out the simulation. The simulation involved adding of the Arduino library of proteus into the simulation software as well as adding of the heart beat sensor. In this simulation stage our main aim was to determine heart rates of individuals with abnormal heart rhythms. This was done by changing of the resistor values within the feedback loop of the circuit while varying the rate of the heart beat using a variable resistor connected to the test pin of the heart beat sensor.
The observations and results carried out were recorded and stored for use in the second simulation stage.

Stage 2: ECG generation using samples of data for different heart beats per minute

In the second stage of the simulation we used data collected from a 60 beat/minute ECG which required a wave form of 543 samples with 457 samples of the first y_data. These were incooperted into the code with y_data in digitized waveform sampled at 1.0 millisecond. This digitized data is converted into an analogue signal with the help of MCP4921 integrated circuit that is performs the digital to analogue conversion. The code that contains the mathematical model with standard mathematical expressions for calculations was compiled and loaded into the Arduino Uno model within the proteus software using the build files of the code (HEX files).(***source code refer to Appendix).***
For further validation of our simulation results, different heart rate values including the abnormal values were feed into the source code to obtain the different ECG wave forms which were acquired at different amplitudes (volts and millivolts).

Simulation circuit.

This figure shows the setup of the circuit simulation and it has the Arduino Uno, resistors, variable resistors and the digital oscilloscope. The digitalized values are fed into the Arduino and are processed and converted into analogy ECG signal which is displayed on the digital oscilloscope.



Specific objective three:

In order to test and validate the functionality of a low-cost portable ECG device using oursimulations.
A graph of Amplitude (A) against Resistance (R) is plotted.

SJ Engineering Africa
Vol. 1 No. 1 (2024): January 2024 Issue
https://doi.org/10.51168/rc3va674
Original Article

RESULTS AND DISCUSSIONS

Table 2: showing obtained from mbarara heart centre.

Month	number of patients	Review	New	diagnostic reports	ecg reports.	death rates	cause of death
Jan	300	88	200	HTN, palpitations, controlled HTN	sinus bradycardia, pvcs, Sinus tacycardia,normal sinus rhythm	5	Associated kidney disease,convulsions, heart failure, and stroke.
Feb	315	156	103	DM11, ischemia, heart failure ejection fraction.	sinus bradycardia, pvcs, Sinus tacycardia,normal sinus rhythm	8	Associated kidney disease,convulsions, heart failure, and stroke.
March	346	78	132	HTN, palpitations, controlled HTN	sinus bradycardia, pvcs, Sinus tacycardia,normal sinus rhythm	3	Associated kidney disease,convulsions, heart failure, and stroke.
April	400	70	123	PUD, palpitations, HTN	sinus bradycardia, pvcs, Sinus tacycardia,normal sinus rhythm	2	Associated kidney disease, convulsions, heart failure, and stroke.
May	378	79	234	DM1,HD1, HTN, heart failure	sinus bradycardia, pvcs, Sinus tacycardia,normal sinus rhythm	2	Associated kidney disease,convulsions, heart failure, and stroke.
June	235	99	134	palpitations, heart failure, difficulty in breathing	sinus bradycardia, pvcs, Sinus tacycardia,normal sinus rhythm	2	Associated kidney disease,convulsions, heart failure, and stroke.
July	234	97	176	controlled Hypertension, referrals, surgery	sinus bradycardia, pvcs, Sinus tacycardia,normal sinus rhythm	6	Associated kidney disease,convulsions, heart failure, and stroke.
August	256	89	186	HTN, palpitations	sinus bradycardia, pvcs, Sinus tacycardia,normal sinus rhythm	0	Associated kidney disease, convulsions, heart failure, stroke.

Source: primary data

SJ Engineering Africa
Vol. 1 No. 1 (2024): January 2024 Issue
https://doi.org/10.51168/rc3va674
Original Article

Data presentation and analysis from the survey conducted at mbarara heart center.

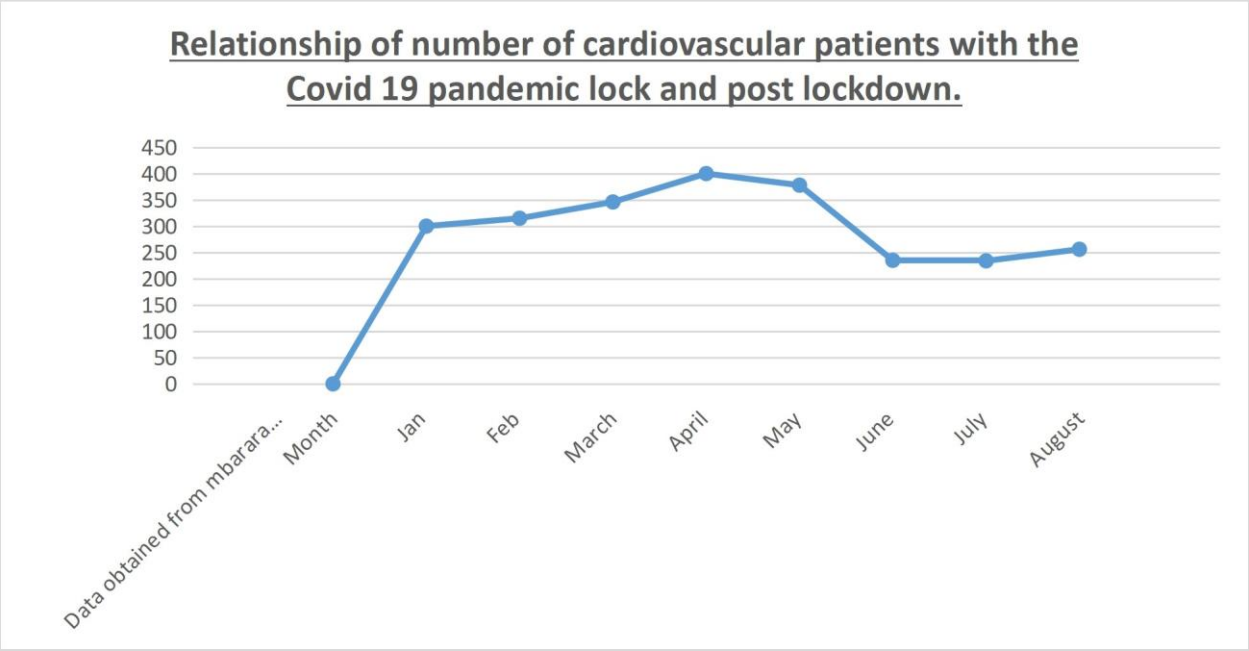


Figure 4 showing the relationship between patients received with months

The figure indicates that the hospital received more than 300 patients in the months when there was no lockdown, however from the time a lockdown as imposed, there was a reduction in the received patients. This is not because they were free from CVDS but there was limited transportation means and access to funds. This means that monitoring of CVD patients becomes difficult for doctors. Therefore, coming up with a lowcost portable ECG would partly solve such challenges.

Stage 1 simulation results.

NOTE: the results from the graphs were summarized in table 2 and further interpretedand discussed.

This figure indicates the waveform at 10k variable resistor at 28%. At the frequency of 37.67m/s,the amplitude of the peak is 107.50mv.

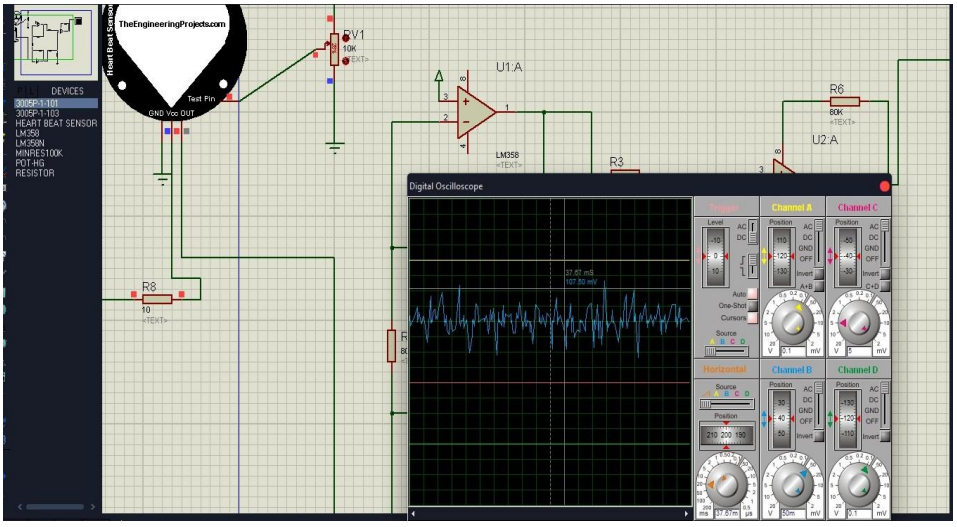


Figure 5: showing waveform at 10k resistor.

This figure indicates the waveform at 20k variable resistor at 28%. At the frequency of 37.67m/s,the amplitude of the peak is 117.50mv.

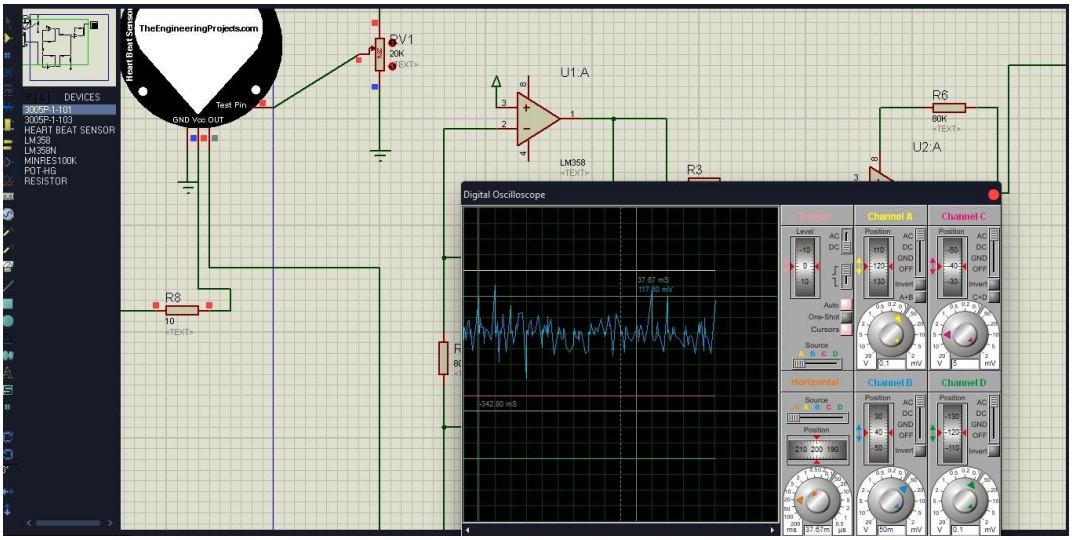


Figure 6: showing the waveform at 20k variable resistor

This figure indicates the waveform at 30k variable resistor at 28%. At the frequency of 37.67m/s,the amplitude of the peak is 127.5 b0mv.

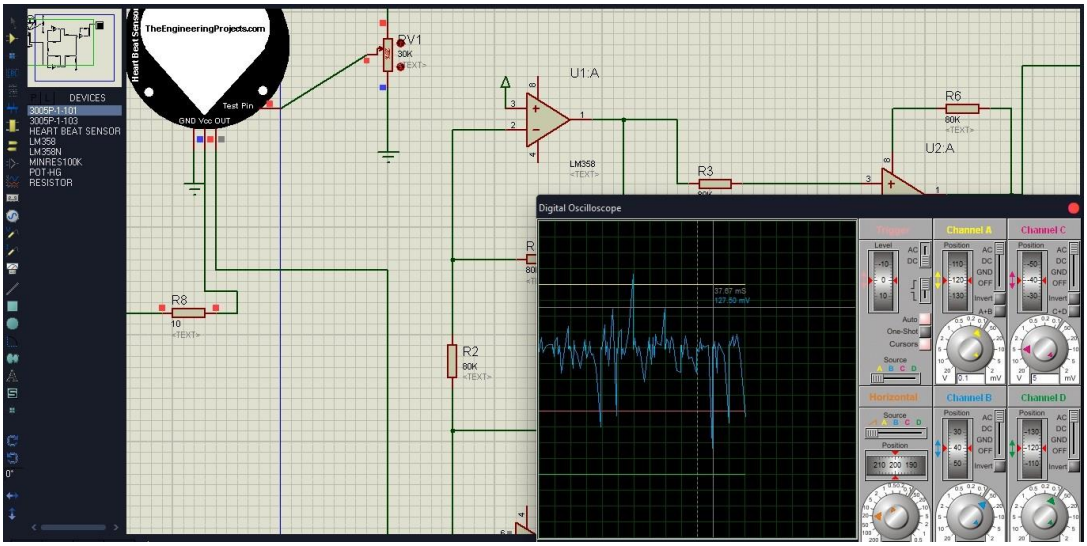


Figure 7: showing the waveform at 30k variable resistor

This table represents results of the waveform at different resistances.

Resistance(ohms)	Amplitude in mv	Frequency in m/s
10k	107.50	37.67
20k	117.50	37.67
30k	127.50	37.67
40k	142.50	37.67

Table 3 shows the summary of results for the first simulation.

Discussion of results for stage 1 simulation.

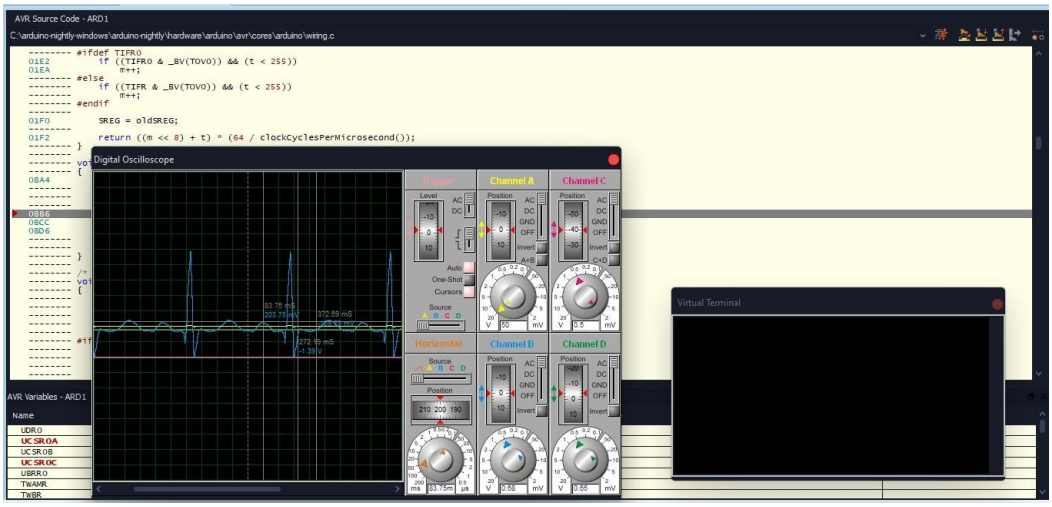
From the table of results, the increase in resistance corresponds to an increase in amplitude for equalpeaks. Occurrence of equal peaks during each recorded heartbeat in the same at the same frequency.Varying the variable resistor should not affect frequency.
Assuming R is our heart's resistance to pump blood.

Explanation of the indifference in the two simulations.

Different ECG sinus waveforms are delivered at different times for example a ventricular filiation has an ECG waveform delivered at 10-30m/s before the T wave [21]. The waveforms have too much noise because the sensor acquires interference from muscle movements, blood flow movements in addition to heartbeats. This propelled us to think of how to reduce the noise. We then opted to feed digitized valves into the ECG source code which is run by the processor and these valves are converted into analog signal to represent the electrical activity of the heart.

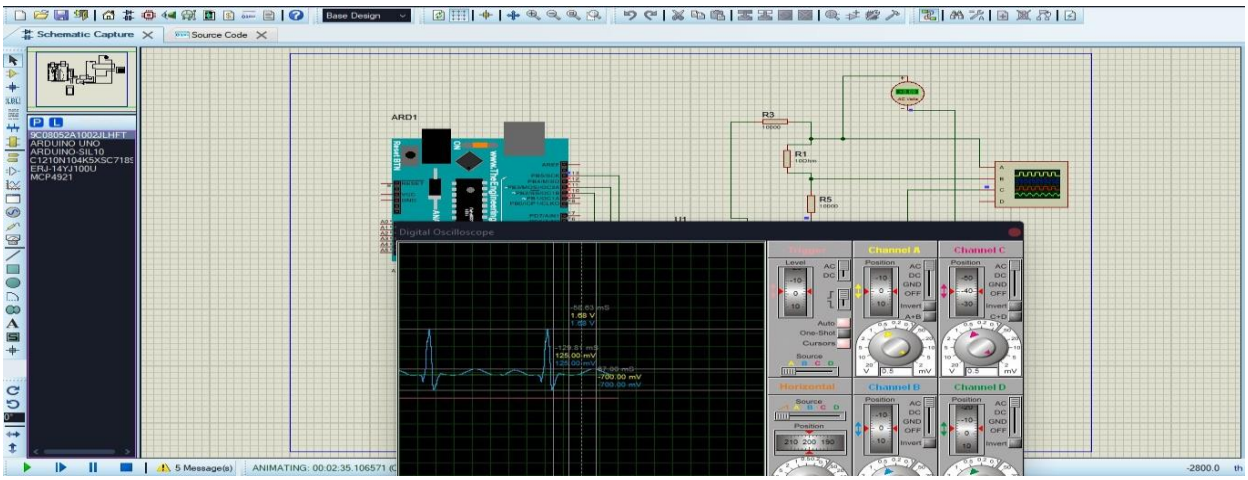
Stage 2 simulation results.

This figure indicates the ECG waveform at 30bpm.



This figure indicates the ECG waveform at 130 bpm.

This figure indicates the ECG waveform at 60 bpm.



This table indicates the summary of results obtained in the second simulation usingdifferent pulse rate results.

Heart rate(bpm)	Time and voltage at T wave	Time and voltage at P wave	Time and voltage at QRS complex.
60	67m/s	238m/s	154.9m/s
30	381m/s at 169 v	83.7m/s at 169.79	293m/s at 1.36mv
130	221m/s at 135mv	205m/s at 339mv	150m/s at 1.32mv

The results were interpreted by analyzing the different waves and comparing them with the normal ECG waveforms. The results indicate the rate at which the wave is delivered at a particular heart rate.

The ECG signal at 60bpm shows a smooth, positive, and a small p wave. It has a long time interval compared to the T wave. The QRS complex duration is 58m/s. the p wave is small because the atria have small muscle mass. Therefore, the normal ECG wave should be > 120m/s, the simulated waveform has a QRS of 58m/s which is less than 120m/s, if the QRS is greater than 120m/s, then the ECG signal is abnormal. Therefore the 60bpm of the simulated waveform indicates a normal sinus rhythm.

The ECG at 40bpm shows a sharp P wave amplitude, positive and large with a QRS complex > 120m/s, 1square unit=100m/s when the paper speed is 25mm/s. therefore since the QRS complex of the simulation is about ¼ of the square unit. This is enough to verify the complex is >120m/s. therefore these results indicate that if a person has a heart rate of 40bpm, it affects the p wave from being a smooth wave to a sharp wave and this means that the ECG is abnormal. Clinically, the person is diagnosed with ventricular bradycardia if the ventricular rate is > 60 bpm. Since the p wave conducts through the atrioventricular node to the ventricles to produce QRS complex in a 1:1 fashion

The ECG at 130bpm shows a smooth P wave and a positive but slightly sharp amplitude. The QRS complex is assumed to be >120m/s since it does not covering the whole big square and this also indicates that the ECG waveform is abnormal. Clinically, the person is diagnosed with sinus tachycardia if the ventricular rate is > 100 bpm.

Vol. 1 No. 1 (2024): January 2024 Issue
https://doi.org/10.51168/rc3va674
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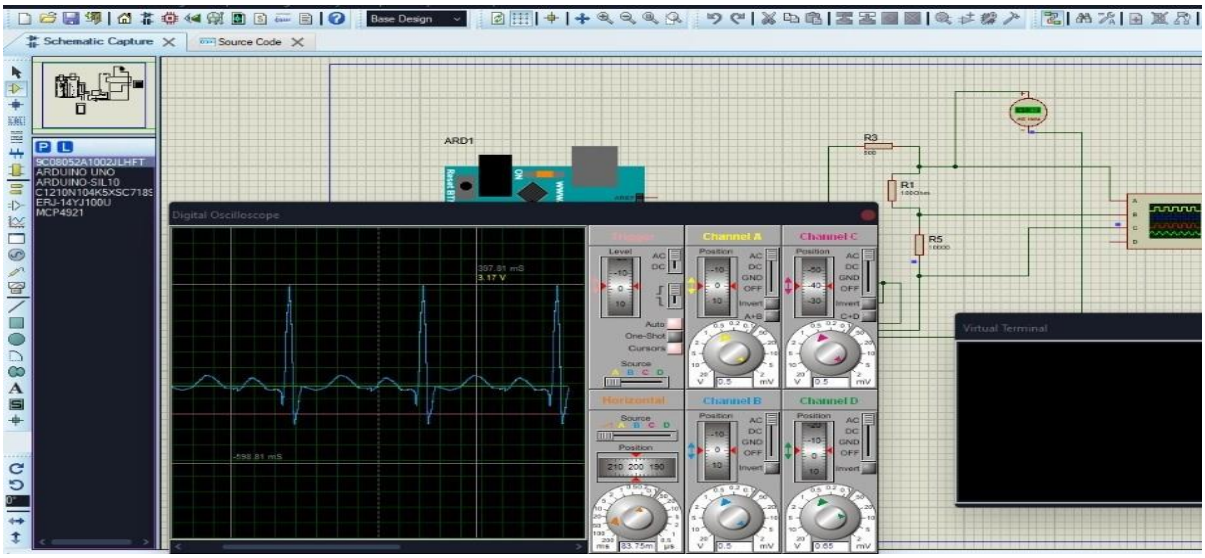
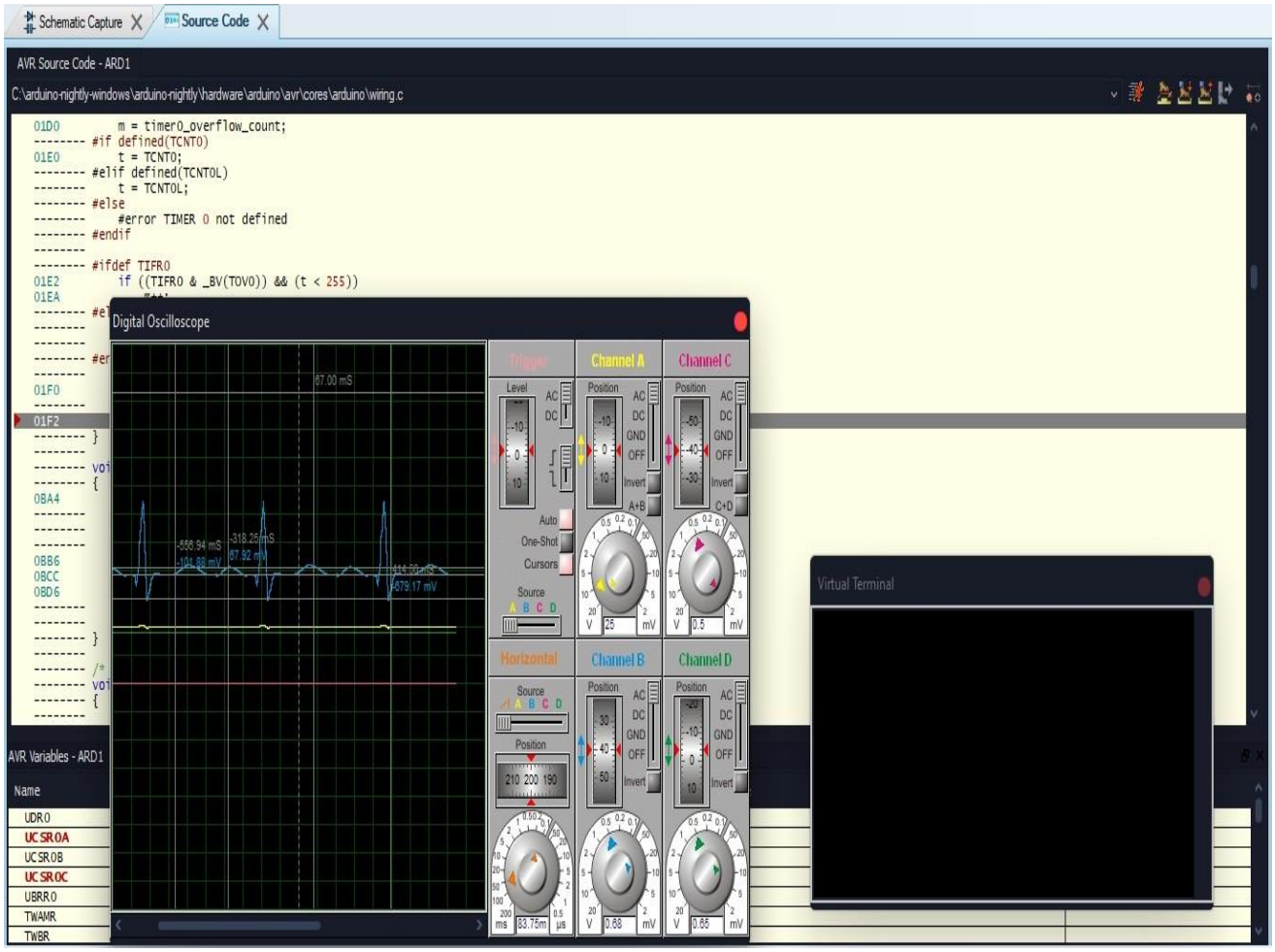


To test and validate our results, the waveforms were varied at different resistances anddifferent plots below describe the results.

This figure indicates an ECG waveform at 30bpm varied at 100k

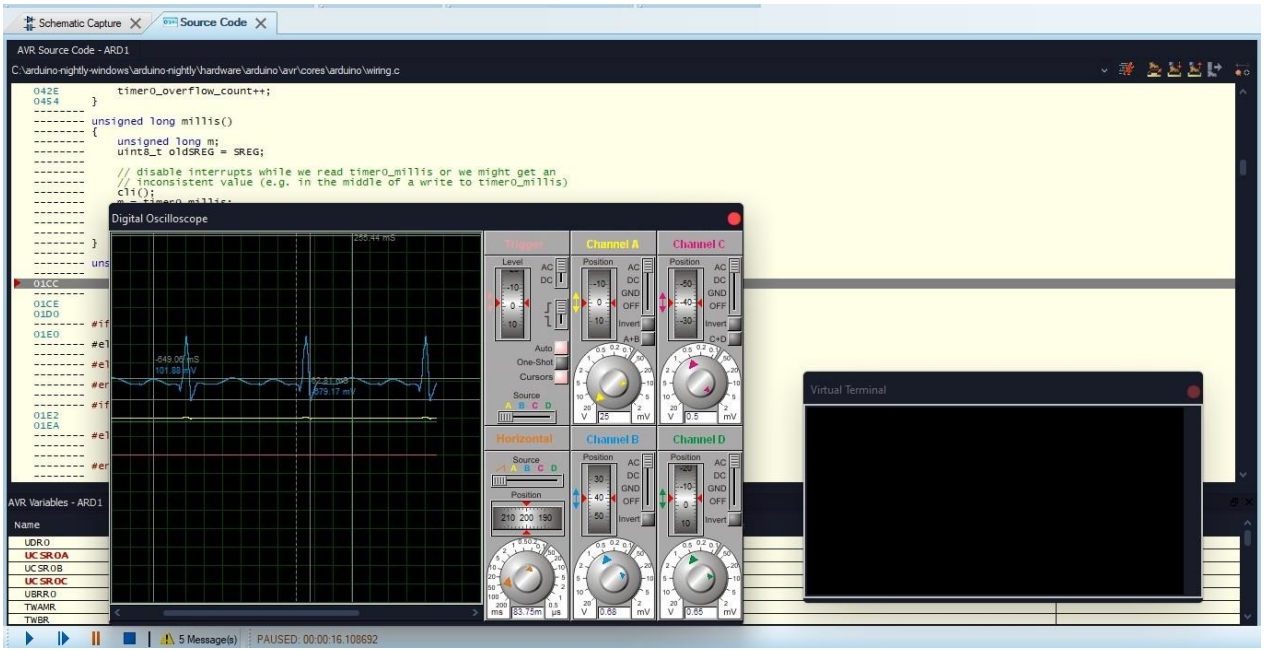
SJ Engineering Africa
Vol. 1 No. 1 (2024): January 2024 Issue
https://doi.org/10.51168/rc3va674
Original Article

This figure indicates the ECG waveform of 60bpm varied at 100bpm



SJ Engineering Africa
Vol. 1 No. 1 (2024): January 2024 Issue
https://doi.org/10.51168/rc3va674
Original Article

This figure indicates an ECG waveform at 110bpm varied at 100k



In all the above cases at 100k resistance, there is a slight variation however the peak amplitude voltages are reduced and there is a smooth wave. The time taken to deliver the waveform ismuch higher compared to when using 80k resistor valves.

In summary, an ECG wave could be split into three sections, p-wave, QRS complex, and T- wave. The P wave records the results from the sinoatrial node which is the heart's natural pacemaker. The QRS is the combination of deflection and contraction of the ventricles muscle. T wave is when the ventricles muscle repolarizes to be ready for the next heartbeat. The digitalized valuesin beats per minute which is the frequency of heart beats inside 60 seconds time period. A healthy heart rate is 60-100bpm at rest. During exercise, it increases to around 110-150bpm and while sleeping, it increases to around 40-60bpm.

If the T-WAVE has a very small amplitude, it could show signs that there is partially clotting inside the patient's coronary artery. It could be concluded that the patient is afflicted by myocardial ischemia (coronary disease). The 130bpm ECG shows that the T-WAVE has a small amplitude compared to the t wave. We could conclude that if a person presents with such kind ofheart rate. She /he could be diagnosed with myocardial ischemia.

Recommendations

The design of a portable low-cost device has been a great milestone for us due to the COVID-19 pandemic. A lot has not been achieved due to limited time, lack of access to materials, lack of internet to perform research, or even the phone network would fail us. Furthermore, we were not able to access our target hospitals and clinics to conduct our survey because of fear of contracting the corona virus.

Therefore, due to the above challenges, we recommend the university have partnerships with different public and private hospitals, different biomedical engineering manufacturing companies, medical equipment supply companies, and medical equipment maintenance workshops to allow students to conduct their research. This is because students could get access to some materials to use in their projects at a limited cost or even use them at a free cost.

Regarding the success of our low-cost portable ECG, we have come up with the physical design due to a lack of components (they have spent a lot of time in the shipping process). We therefore decided to carry out a simulation of low-cost portable ECG using some of the components we wanted to use in the physical design.

We recommend further research in incorporating the AD8232 and the ECG simulator libraries in proteus software to be able to extract signals so that all three leads can be displayed on the digital oscilloscope.

Conclusion.

The major aim of the project was to design and build a low-cost portable ECG device using the specific objectives. We were able to partly achieve our objectives by carrying out simulations to mimic the design of the physical prototype using Arduino-based microprocessor. Much as we have not yet designed and tested the physical prototype of the ECG device, the simulated project has worked with a desirable

result. The digital oscilloscope can record the electrical activityof the heart using the digitalized heartbeat values controlled by the microprocessor and it plots the analogy data in the form of the graph on the oscilloscope. Regretfully, even though the ECG wave is obtained, a method of using ECG simulator and ECG module libraries on proteus software is still not found. We hope that in the future, the method to install the ECG simulator and AD8232 library in proteus will be found to simulate ECG projects in proteus and be able to mimic physical designs.

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SJ Engineering Africa
Vol. 1 No. 1 (2024): January 2024 Issue
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