Development of a Real-Time Integrated Electrocardiogram (ECG) and Reflectance-Based Pulse Oximetry System

Luckson Gorondondo
Medical Physicist (Allied Health Practitioners Council of Zimbabwe, and Radiation Protection Authority of Zimbabwe)

Abstract

Cardiovascular disease (CVD) is one of the primary causes of sudden cardiac death in Africa. Cardiac anomalies can be detected using an electrocardiogram (ECG), but the most difficult aspect of CVD is detection during its early stages. In addition to monitoring the heart using ECG, heart rate and blood oxygen saturation (SpO_2) are also important indicators related to the heart-pulmonary system since the two variables provide an indication of the overall functionality of the heart. Insufficient technologies for monitoring these parameters have been documented (especially in LMIC regions and rural areas) leading to late detection. The objective of this study was to create a low-cost 3-lead ECG signal detecting system and a pulse oximeter that could detect the likelihood of CVD in real time. The design of the device with LCD and DSO138 oscilloscope output is described in this study. Five units were used to create the device: ECG electrodes attached to an AD8232 ECG sensor module; ECG filter system; DSO138; MAX30100 heart rate and oxygen saturation sensor, and a power source. The results revealed that the portable device interprets the ECG signal from the 3-lead ECG system satisfactorily. The pulse oximeter system is made from a MAX30100 sensor which displays patient heart rate and oxygen saturation levels on an alphanumeric LCD screen. The designed system was successfully compared against a standard 3-lead ECG system and an internationally approved Oxiline Pulse 7 Pro pulse oximeter. The system developed in this study was able to function according to the design, measuring heart rate, and blood oxygen saturation, and displaying ECG waveforms. According to the test findings using the designed pulse oximeter system, heart rate measurements resulted in an error value of -0.70% and -0.21% in males and females, respectively, as well as 1.28% and 0.10% for SpO_2 results in males and females, respectively after comparison. For a much better assessment of CVD, there is a need to integrate the system with a GSM module to allow for the transmission of ECG

signals, heart rate, and SpO_2 patient data through mobile phones and the internet for remote and automated monitoring.

Keywords: electrocardiogram, heart rate, SpO_2, pulse oximetry system, automation, CVD

ACRONYMS

ECG	Electrocardiogram
CVD	Cardiovascular disease
LMIC	Low to medium income country
GSM	Global system for mobile communication
LCD	Liquid crystal display
NCD	Non communicable disease
CMD	Cardiometabolic disorders
HR	Heart rate
BPM	Beats per minute
WHO	World Health Organization
PAD	Peripheral artery disease

Introduction and background

Cardiovascular disease (CVD) has long been one of the primary causes of sudden death in many nations, both developed and developing. In the United Kingdom, cardiovascular disease has been a significant and ever-growing problem, and it has been responsible for almost one-third of all deaths, leading to significant morbidity (Stewart, Manmathan & Wilkinson, 2017). In developing countries, more cases of CVD have been attributed to a change in lifestyle which introduces novel risk factors for the disease (Stewart, Manmathan & Wilkinson, 2017). According to Ruan et al. (2018) approximately 17.9 million people died from CVD in 2015 in the entire world. By 2030, it is anticipated that at least 22.2 million people will die from cardiovascular diseases each year, with low and middle-income countries (LMICs) accounting for over 75% of CVD deaths (Ruan et al., 2018).

The term "cardiovascular disease" refers to a group of diseases that include cerebrovascular disease and rheumatic heart disease among others (Stewart, Manmathan & Wilkinson, 2017). Cardiovascular diseases were identified as the top cause of death among non-communicable diseases (NCDs) in 2021 (Made, Nonterah,

Tlotleng, Ntlebi, 2021). Poor diets have contributed to an increase in CVD cases in Zimbabwe, and the World Health Organization (WHO) cites these factors as the top worldwide health hazards, especially for CVD (Morera, Marchiori, Medrano & Defagó, 2019). In a study conducted by (Mutowo, 2015), the data gathered illustrated that cardiometabolic disorders (CMDs) and accompanying mortality are on the rise in Zimbabwe. The authors underlined the urgent need for cost-effective preventative interventions to lessen the burden of CMDs and backed the realignment of health policy decisions. In the quest to reduce the burden of CVD, insufficient primary care, including access to physicians, technologies, and treatments, have been cited as major causes of cardiovascular diseases related deaths (Ertola, Figueira, Carlsen, Palaniappan & Rondini, 2016).

Matiashe (2019) noted that, an ECG test in Zimbabwe was pegged at US$240, and this was not accessible to many people, especially those who live in rural areas. In the article, Matiashe (2019) pointed out that cardiac tests, which include ECG tests in Zimbabwean public hospitals, were only done at Parirenyatwa, Harare Central and Mpilo Central hospitals due to insufficient portable technologies, forcing many patients to seek services in private institutions and out of the country, making ECG tests inaccessible to most remote and rural parts of Zimbabwe. Heart rate and blood oxygen saturation measurements are also critical in cardiovascular monitoring. Currently these measurements are not being done frequently due to inaccessibility of equipment in rural Zimbabwe. Ramachandran and Bashyam (2017) developed a real time ECG signal monitoring system for telemedicine application, with the only drawbacks being portability and cost as it was integrated with a laptop. Another study conducted by Fezari, Bousbia-Salah and Bedda (2008) , examined an embedded system based on a microcontroller for real-time interpretation of ECG data, which was built and tested on various heart diseases. The system was made for telemedicine and the main goal was to reduce hospitalisation and assistance cost through early monitoring of patients. Hence, the aim of this study is to develop a simple system that is suitable for ECG signal monitoring.

Problem statement and justification

Insufficient technologies for monitoring heart signals, heart rate and blood oxygen saturation have been mentioned among reasons for lack of early diagnosis of CVDs

leading to increased number of deaths in LMICs especially in rural areas. Reasons behind lack of these technologies have been prohibitive cost, inaccessibility, and unavailability. The development of this affordable machine will go a long way to improving cardiovascular disease monitoring, especially in rural areas where these services are inaccessible because of cost and lack of infrastructural technologies. ECG tests would now be accessible in small clinics at cheap prices affordable to people living in LMIC's. This would improve early detection of cardiovascular diseases and improved patient care, thereby improving the quality of life of the population. The system would offer an advantage of ECG monitoring, measurement of blood oxygen saturation and heart rate at the same time.

Aim

The aim was to develop a cheap real time integrated electrocardiogram (ECG) and pulse oximeter system to be easily used in the villages, clinics, or houses, due to the small size and ease of use of the device.

Objectives

i) To design and develop a portable 3-lead ECG monitoring system.

ii) To design and develop a heart rate and blood oxygen saturation measuring system.

iii) To integrate the two systems into one device.

Literature review

Cardiovascular diseases are currently diagnosed using a variety of technologies, such as the electrocardiogram (ECG), also known as the electrocardiogram (EKG in German), among other methods. The electrocardiogram is an old technology but still widely used because its quick, painless, non-invasive, can spot abnormal heart rhythms and does not use ionising radiation (Ehnesh, Abatis & Schlindwein, 2020). An electrocardiogram (ECG) is a medical test that tracks the electrical activity produced by the heart while it contracts in to identify cardiac issues and anomalies. The electrical activity of the heart is supported by excitable muscle tissue's capacity to quickly alter its membrane permeability to sodium (Na^+) and potassium (K^-) ions. These ions move across the cell membrane and produce a fluctuating electric field that resembles the electrical activity of the heart. When these ions migrate across the cell membrane, they create a changing electric field that mimics the heart's electrical activity. The

electrical signals are picked up using electrodes linked to the patient, which are then amplified and shown on a cathode ray oscilloscope (CRO) to assess the patient's heart rate and other health information (Shakhreet, 2015). Figures 1 (a and b) illustrate the general anatomy of the heart in 3-D and cross-sectional view, respectively.

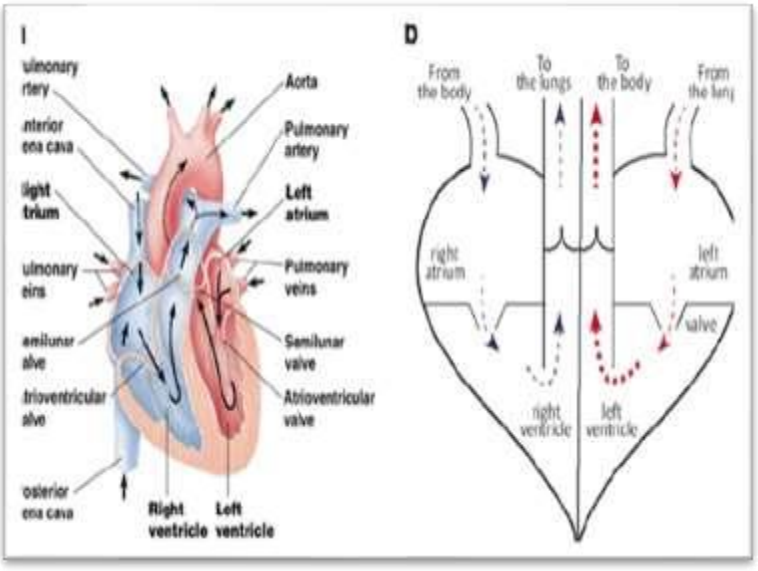

Figure 1: (a) 3D anatomy of the heart (b) cross-section of the heart

(Source: Heart anatomy, 2020)

Cardiovascular disorders can be identified using ECG testing (Electrocardiogram & Cardiovascular, 2021). A typical ECG wave as shown in Figure 2 is formed by the cyclical changes in the polarisation of the heart cell (Price, Cardiologist, Mary & Wight, 2016).

Table 1: Sections of an ECG trace

Section of Electrocardiogram	Section
P - Wave	Atrial Excitation
QRS - Complex	Atria Repolarisation + Ventricle Depolarisation
T - Wave	Ventricle Repolarisation
P - Q Interval	Excitation Timing Delay

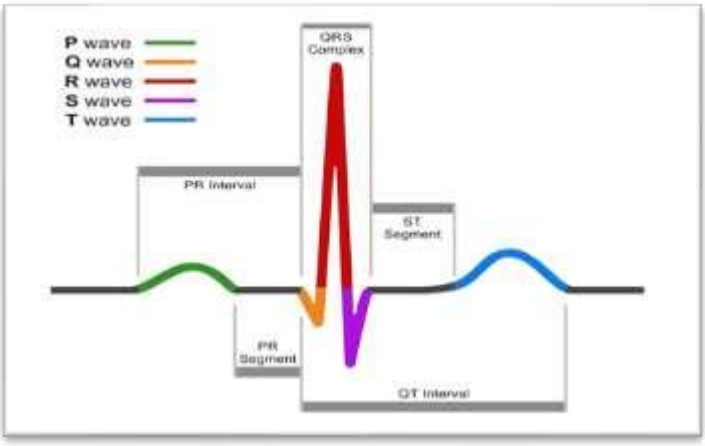

Figure 2: Standard normal ECG Waveform
(Source: David Hudon, 2021)

From an ECG graph, a clinician can detect enlargement of the heart, clogging up of heart blood supply, previous heart attacks, and heart failure (Sunehra & Siddireddygari, 2020).

Contractions in the heart walls produce electrical currents and create various potentials throughout the body, resulting in heart electrical signals. By putting electrodes on the skin, this electrical activity can be detected and recorded in an ECG. The electrical signal originates in the right atrium's sinoatrial node and travels to the right and left atria, causing contraction and subsequent blood pumping into the ventricles. The ECG records this electrical output as the P wave. Figure 2 shows a standard ECG trace for a normal human heart. P, QRS, and T waves are three vertical waves that show the depolarisation (atria contracting as a P wave, followed by the ventricles contracting as a QRS wave), and repolarisation, respectively, of the ventricle. In a typical ECG trace, a vertical P wave appears first, followed by the QRS complex and then a T wave. Atria repolarisation (relaxation) is weak and covered by QRS on the ECG trace, which has a straight line at zero voltage that represents the baseline known as the isoelectric line (Electrocardiogram & Cardiovascular, 2021).

Pulse oximetry

Heart rate (HR) and blood oxygen saturation (SpO_2) are crucial markers that are directly connected to the heart-pulmonary system in addition to heart health monitoring utilising the ECG approach. The two variables give an indication of the overall functionality of the heart especially in old people and pregnant women hence their

importance. A pulse oximeter is a medical device that can be used to noninvasively detect heart rate and indirectly monitor the patient's oxygen saturation level in the blood (Tso, Currie, Gilmore & Kiat, 2015). In pulse oximeters, 660 nm (red) and 940 nm (blue) light wavelengths are used to illuminate the skin and detect variations in the amount of light that is absorbed by oxygenated and deoxygenated (reduced haemoglobin) blood (Jubran, 2015). Several researchers have looked into designs of pulse oximeters; however, low-cost pulse oximeter designs for LMICs that provide unfiltered photo-plethysmograms (PPGs) are still unavailable (Fu & Liu, 2015) hence the motivation to carry out this research and to integrate the pulse oximetry system together with an ECG system for quick, convenient patient monitoring.

Reflective-mode pulse oximetry has been steadily rising in popularity as a means of monitoring oxygen saturation in blood since it can be used on the forehead, feet, chest, and wrists, and it does not need a thin measuring site. Despite current research into reflectance-based pulse oximeters, transmittance-based oximeters remain popular due to their high accuracy and stability, ease of signal processing and use (Lee, Ko & Lee, 2016). The main drawback with transmittance-based pulse oximetry system is the limited areas of the body where the sensor can be placed (Abedalmoniam & Fadul, 2017). This type of oximeter is normally paced on the ear or the finger.

Heart rate

According to Diaz, Casas, and Pallas-Areny (2010), heart rate provides information on the condition of the heart and assists in the diagnosis and evaluation of cardiovascular system problems (Díaz, Casas & Pallas-Areny, 2010). In a clinical environment, heart rate is observed in conjunction with other controlled parameters such as blood pressure, heart rate, and electrocardiogram (ECG). The heart beats to carry cell waste away from the muscles and to provide them with oxygen-rich blood. The heart needs to work harder to conduct these functions as more muscles are employed, which makes it pump blood more quickly. In order to use the data to check for heart problems, heart rate (cardiac rate) monitors are used to record heartbeats and determine the number of beats per minute (BPM). In order to use the data to check for cardiac abnormalities, monitors are used to capture heartbeats and determine the number of beats per minute (BPM). Electrical and optical heart rate monitors are the two types of heart rate monitors available (Hashem, Shams, Kader & Sayed, 2010).

On average, adult males have a resting heart rate of 70 to 72 beats per minute and adult females, 75 to 82 beats per minute (Ciklacandir, 2017). Depending on one's level of fitness, age, and heredity, individual heart rates vary significantly. By taking one's pulse, which may be done with sophisticated medical equipment or just by putting one's fingertips against an artery (usually on the wrist or neck), one can measure their heart rate (Ciklacandir, 2017). Although there are other well-known and established ways to measure heart rates, such as the phonocardiogram (PCG), electrocardiogram (ECG), blood pressure wave form, and pulse meters, it is generally agreed that auscultation-listening to heartbeats with a stethoscope-is a more precise and accurate method (Tai & Chien, 2005). The main disadvantage of other techniques being used is the issue of cost as they are expensive. Other cost-effective approaches for measuring heart rate using wearable sensors include an acoustic sensor encased in an air pillow and another technique is finger modelling (Rhee, Yang & Asada, 1999) however both methods are prone to noise and movement of subject and arteries.

Complications arising from cardiovascular diseases

The most feared side effect of CVD is death and, despite significant advances in recent years, CVD still ranks among the world's top causes of death as a result of the disease's increased prevalence in the population (Dunbar et al., 2018). Other challenges include the need for prolonged hospital stays, physical impairment, and growing healthcare costs, which are crucial and will be a priority for health-care policymakers as they are anticipated to rise in the coming decades (Dunbar et al., 2018). When a person has heart failure with a blood ejection fraction that is less than 35%, they are at a substantial risk of developing life-threatening arrhythmias. The implantation of an implanted cardioverter defibrillator (ICD) is advised by current recommendations for patients with symptoms that are comparable to a New York Heart Association (NYHA) Class II-IV, despite the use of maximally tolerated pharmaceutical treatment (Yancy et al., 2017). Strokes can have long-lasting or transitory effects that are very debilitating, such as dysarthria or aphasia, dysphagia, localised or widespread muscular weakness, or paresis. Due to hemiplegia, they can leave a person completely bedridden, with extra negative effects such an elevated risk of thromboembolic events and/or urinary tract infections (Carvalho-Pinto & Faria, 2016; Bovim, Askim, Lydersen, Fjærtoft & Indredavik, 2016). People with PAD have an increased risk of dying from any cause when compared to individuals without signs of peripheral disease (IJsselmuiden & Faden, 1992). Physical

restrictions, persistent wounds, and limb ischemia are additional side effects of PAD (Ponikowski et al., 2016; Ruan et al., 2018).

Methodology

A circuit diagram of the ECG system developed is shown in Figure 3. The circuit was drawn and simulated in microcap software. The output signal was fed to the AD8232 sensor module for further processing before the signal was displayed on the CRO screen.

The bio signal conditioning techniques and sequences described below are developed to successfully reduce unnecessary noise while maintaining the valuable components of ECG signals:

i) An instrumentation amplifier is used to amplify the raw ECG signal in order to increase the signal voltage level.
ii) The DC offset those forms between electrodes is removed using a high-pass filter.
iii) A low-pass filter is employed to filter out high-frequency background noise.
iv) A notch filter is used to get rid of power line interference.

The filtered analogue ECG signal is then digitalised for computer display and/or further digital signal processing and analysis.

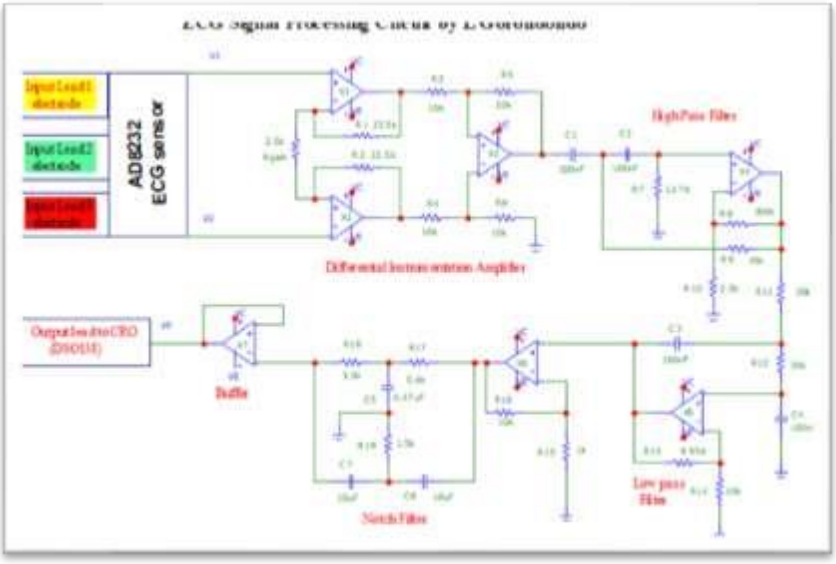

Figure 3: ECG Signal processing circuit without electrodes

ECG simulation in microcap

Figure 4 shows the ECG signal obtained from microcap software during simulation using a 1.5 mV signal.

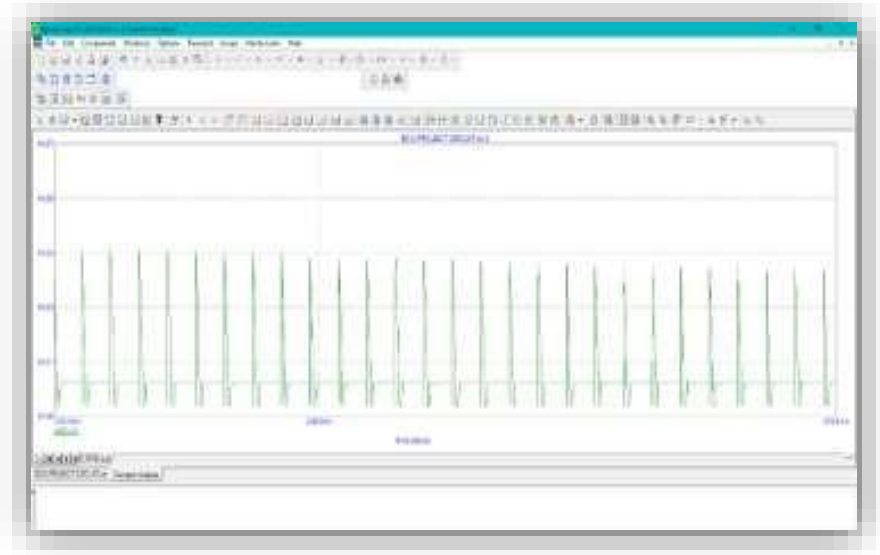

Figure 4: ECG signal simulation in microcap

Pulse oximeter system design

The pulse oximeter system was designed using a MAX30100 sensor. Since the MAX30100 is a sensor solution that combines pulse oximetry and a heart rate monitor, it was chosen as the main sensor. The pulse oximeter has light sensors incorporated in two LEDs (red and infrared) and a photodiode part of the MAX30100 sensor, which is positioned between a patient's body parts, such as a finger or earlobes. The two LEDs are coupled and positioned so that the photodiode receives the light and, depending on the type of oximeter probe, they alternately transmit or reflect light through the anatomy. The photodiode transforms the incoming light that has not been absorbed or dispersed by the body into an analogue electrical signal that is delivered to the analogue pin of the Arduino Uno module. The Arduino module contains an AT Mega 328p microcontroller that performs computations and displays the heart rate and blood oxygen saturation readings on the liquid crystal display (LCD) module. The LCD contrast is adjusted using a potentiometer.

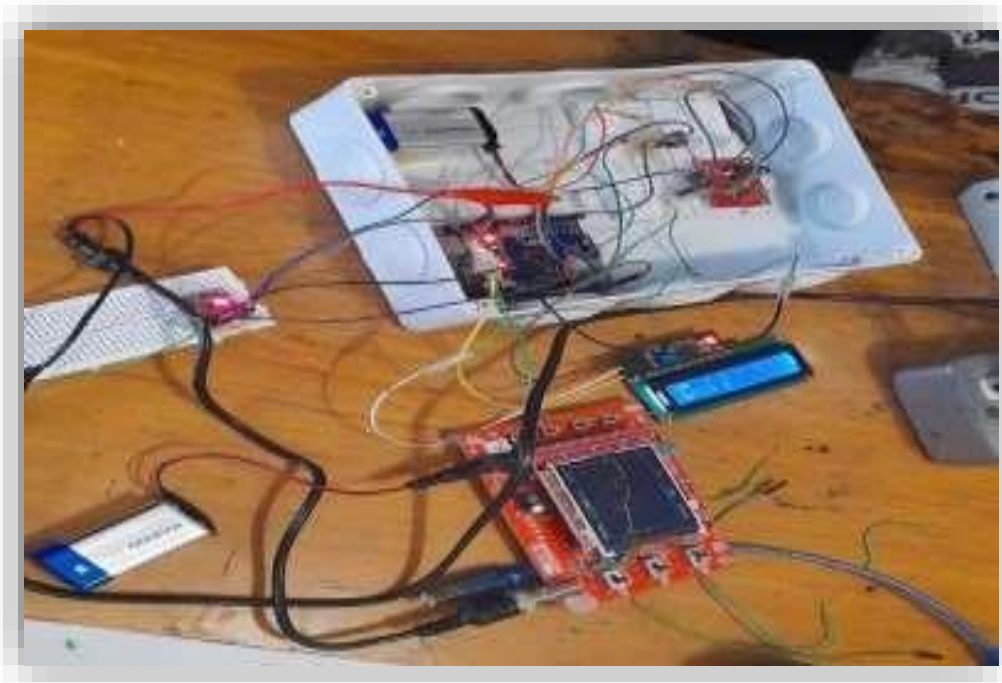

Figure 5: Fabrication of the ECG system

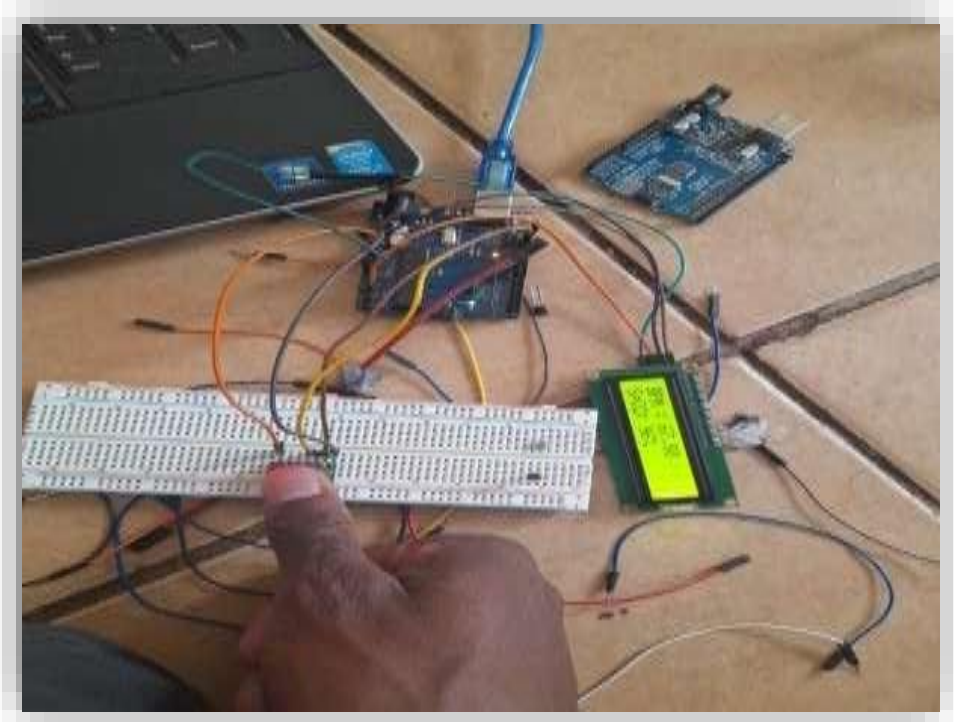

Figure 6: Fabrication of the pulse oximeter system

Figure 7: Integration of the ECG and pulse oximeter systems

Heart rate and SpO_2

A sample of twenty people was chosen for heart rate and oxygen saturation data collection and analysis. Ten males and ten females were chosen randomly. Males are said to have a heart rate between 70 and 72 while that of females is between 75 to 82 (Ciklacandir, 2017). People without any history of heart diseases were chosen to measure their heart rate and blood oxygen saturations. The selected people in the sample were given code names from A to J without any specific order followed for anonymity. The sample was divided into two groups: group A (males) and group B (females). The two groups were then compared independently. Each person's heart rate and blood oxygen saturation values were obtained from the designed pulse oximeter system and also from a standard FDA international pulse oximeter (Oxiline Pulse 7 Pro pulse oximeter) currently in use in many hospitals in Zimbabwe (Ciklacandir, 2017). T-tests were used to statistically analyse the data to determine if there was a significant difference between the means of data collected using the designed pulse oximeter system and the Oxiline Pulse 7 Pro pulse oximeter. A t-test was chosen for analysis because the data was independent, approximately normally distributed and the sample size was sample. Two tailed t-tests were carried out at 95% level of confidence ($\alpha = 0.05$).

Sample 1 size (n_1) = 10

Sample 2 size (n_2) = 10

Degrees of freedom ($n_1 + n_2 - 2$) = 18

Level of confidence = 95%

The t-test value and standard error were calculated according to statistical formulars in equations 1 and 2 respectively.

$t = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{s_p^2 (\frac{1}{n_1} + \frac{1}{n_2}}}$ ……	Eq 1

$S_p^2 = \frac{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}{n_1 + n_2 - 2}$ … … … … … …	Eq 2

Where:

$\bar{x}_1$ is the mean for sample 1

x_2 is the mean for sample 2.

S_p^2 is the pooled standard deviation.

s_1 is the standard deviation for sample 1

s_2 is the standard deviation for sample 2.

n_1 is the size of sample 1.

n_2 is the size of sample 2.

Results

ECG results

The ECG system was tested on the researcher and the ECG trace obtained and displayed on a DSO138 oscilloscope is shown in Figure 8 below.

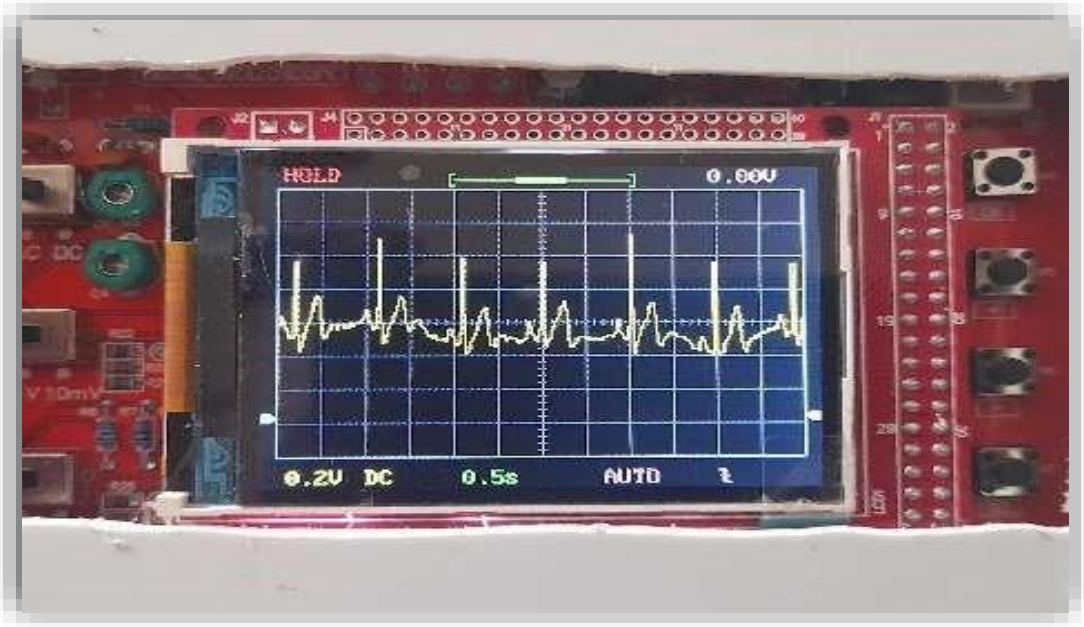

Figure 8: ECG trace obtained using the designed system

Heart rate and SpO_2 results

Table 2: Heart rate data for ten randomly selected male persons

Males	Designed pulse oximeter prototype	Oxiline Pulse 7 Pro pulse oximeter	% Difference
Person	**Heart Rate**	**Heart rate**	
A	69	70	1.43
B	71	72	1.39
C	71	72	1.39
D	73	70	-4.29
E	75	71	-5.63
F	70	70	0.00
G	70	68	-2.94
H	72	73	1.37
I	76	73	-4.11
J	68	71	4.23
Average	**71.5**	**71.0**	**-0.70**
Standard deviation	**2.55**	**1.56**	**3.27**

$t_{calculated}$ = 0.53

$t_{0.025,18}$ = 2.10

$t_{calculated} < t_{critical}$, therefore, we fail to reject the null hypothesis.

Table 3: Heart rate data for ten randomly selected female persons

Females	Designed pulse oximeter prototype	Oxiline Pulse 7 Pro pulse oximeter	% Difference
Person	**Heart Rate**	**Heart rate**	
A	76	78	2.56
B	75	78	3.85
C	74	76	2.63
D	73	75	2.67
E	79	78	-1.28
F	80	80	0.00
G	81	78	-3.85
H	82	83	1.20
I	76	79	3.80
J	75	76	1.32
Average	**77.1**	**78.1**	**1.28**
Standard deviation	**3.14**	**2.28**	**2.42**

$t_{calculated}$ = -0.81

$t_{0.025,18}$ = -2.10

$t_{calculated} > t_{critical}$, therefore, we fail to reject the null hypothesis.

There is no significant difference in heart rates measured by the two instruments for both males and females., therefore the null hypothesis was taken as true.

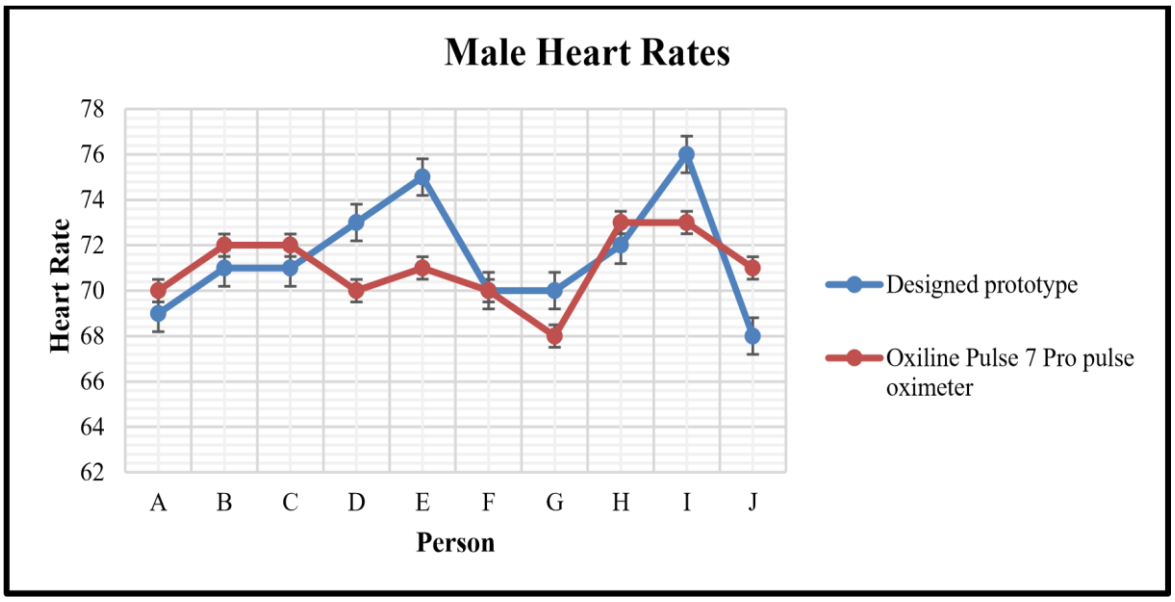

Figure 9: Graphical comparison of male heart rates as measured by the designed prototype and a Oxiline Pulse 7 Pro pulse oximeter

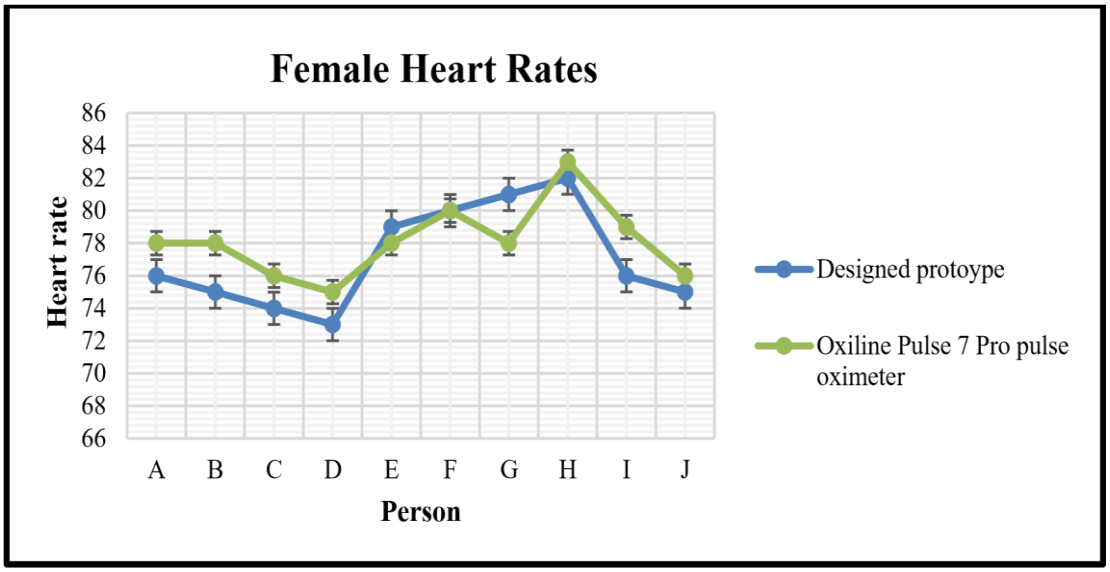

Figure 10: Graphical comparison of female heart rates as measured by the designed prototype and a Oxiline Pulse 7 Pro pulse oximeter

Two-sided t-test workings for SpO_2

Degrees of freedom = $(n_1 + n_2 - 2) = 18$

Level of confidence = 95%

Table 4: Oxygen saturation data for ten randomly selected male persons

Males	Designed pulse oximeter prototype	Oxiline Pulse 7 Pro pulse oximeter	% Difference
Person	**SpO_2**	**SpO_2**	
A	95	95	0.00
B	96	96	0.00
C	96	95	-1.05
D	97	98	1.02
E	99	98	-1.02
F	98	98	0.00
G	99	96	-3.13
H	96	97	1.03
I	95	97	2.06
J	99	98	-1.02
Average	**97.0**	**96.8**	**-0.21**
Standard deviation	**1.63**	**1.23**	**1.45**

$t_{calculated}$ = 0.31

$t0.025,18 = 2.10$

$t_{calculated} < t_{critical}$, therefore, the null hypothesis was not rejected.

Table 5: Oxygen saturation data for ten randomly selected female persons

Females	Designed pulse oximeter prototype	Oxiline Pulse 7 Pro pulse oximeter	Percentage difference
Person	**SpO2**	**SpO2**	
A	98	95	-3.16
B	98	96	-2.08
C	97	98	1.02
D	97	97	0.00
E	96	95	-1.05
F	98	98	0.00
G	96	99	3.03
H	96	96	0.00
I	94	96	2.08
J	97	98	1.02
Average	**96.7**	**96.8**	**0.10**
Standard deviation	**1.25**	**1.40**	**1.85**

$t_{calculated}$ = -0.28

t0.025,18 = -2.10

$t_{calculated} > t_{critical}$, therefore, the null hypothesis was not rejected.

There is no significant difference in blood oxygen saturations measured by the two instruments for both males and females.

Blood oxygen saturation graphical analysis

Figures 11 and 12 show a graphical comparison of percentage of oxygen in blood as measured by the designed prototype and an Oxiline Pulse 7 Pro pulse oximeter for both male and female samples, respectively.

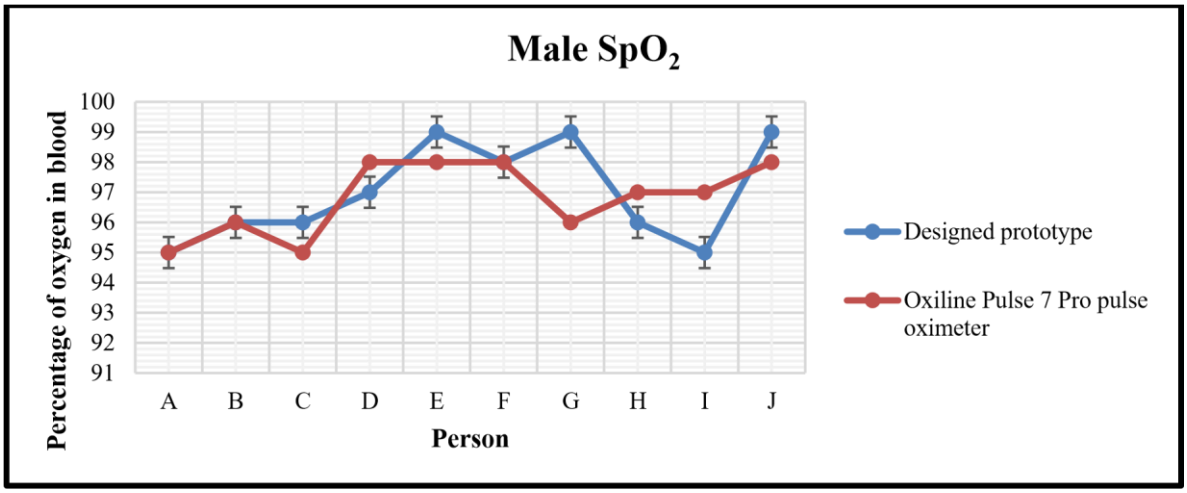

Figure 11: Graphical comparison of male percentages of oxygen in blood as measured by the designed prototype and an Oxiline Pulse 7 Pro pulse oximeter

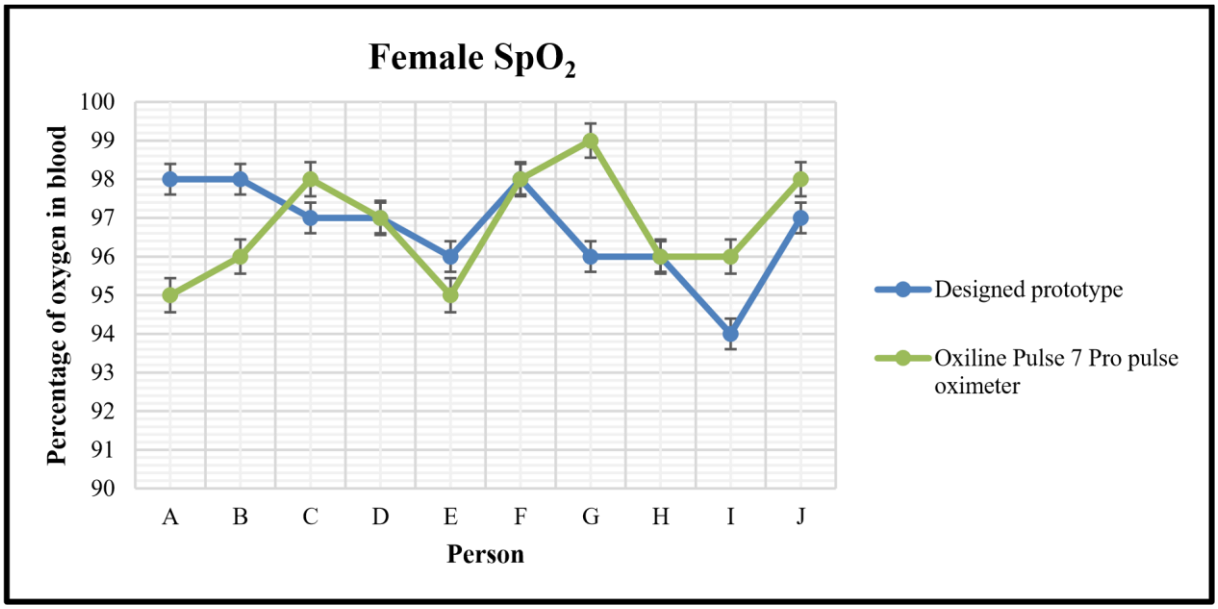

Figure 12: Graphical comparison of female percentages of oxygen in blood as measured by the designed prototype and an Oxiline Pulse 7 Pro pulse oximeter

There are no significant differences for the data of heart oxygen saturation in blood collected for males and females using the two devices.

Discussions

ECG signals from electrodes have millivolt-level amplitudes, hence they need to be amplified. Instrumentation amplifiers are used by amplifier circuits to transform the difference between signals to an output voltage. The proposed device's analogue front-end circuitry is made up of three integrated circuits: a low noise operational amplifier (OPA134), a low offset operational amplifier (TL082), and an instrumentation amplifier (AD8220). The instrumentation amplifier AD8220 with a gain of 20 dB increased the difference between two signals obtained from the electrodes. By placing a 2.5 k resistance across the AD8220's gain resistor pin, a gain of 20 dB was attained. A high-pass filter with a cut-off frequency of 0.033 Hz was created to eliminate extraneous noise below the frequency of the ECG. The signal's 20-dB gain was insufficient for the DSO138 oscilloscope to display the signal; thus, a low noise amplifier was employed to boost the overall gain by 20-dB. A low-pass filter with a cut-off frequency of 150 Hz was created to only allow the frequency of the ECG in order to avoid high-frequency noise from interfering with the data gathering process. TL082 JFET operational amplifier was used to create a second high-pass filter with a

20-dB gain to increase the amplification and noise filtering. Because it has a limited frequency bandwidth (0-200 kHz) and is inexpensive (about US$15) compared to TFT displays, a DSO138 cathode ray oscilloscope was used for this portable ECG. As a result, a DSO138 is appropriate for affordable ECG monitoring devices. Although the ECG analogue front end also amplifies the circuit noise and 50-Hz noise interference, the results of the ECG signals were amplified to have a peak-to-peak value of 500 mV, which could be seen on the oscilloscope. A 50-Hz filter is necessary for the system to be further improved so that the ECG signal reading is not dominated by power supply noise interference.

The device built in this study worked as intended, measuring heart rate and blood oxygen saturation and displaying ECG waveforms. According to the test findings using the designed pulse oximeter system, heart rate measurements resulted in an error value of -0.70% and -0.21% in males and females, respectively, as well as 1.28% and 0.10% for SpO_2 results in males and females, respectively after comparison. For a much better assessment of CVD, there is a need to integrate the system with a GSM module, to allow for the transmission of ECG signals, heart rate, and SpO_2 patient data through mobile phones and the internet for remote and automated monitoring.

Recommendations

A low-cost electrocardiogram and pulse oximeter system was designed successfully and compared against standard 3-lead ECG system and an internationally approved transmittance-based pulse oximeter (Oxiline Pulse 7 Pro pulse oximeter). For better and more accurate results, the system must be thoroughly documented and tested on a large sample size. This project met its aims, yet there are certain areas where some aspects might be improved. To begin with, the connections that connected the ECG-sensor and the amplification circuit were not the best. It is advised that insulated cables be used to reduce interference from electromagnetic radiation, and that the cables be flexible to make the patient more comfortable. Because the ECG electrodes used in this experiment were not the best, it is advised that salty gel be placed between the electrodes and the skin to minimise resistance between them. Using better ECG electrodes, it is feasible to generate a crisper ECG trace than the one acquired in the project.

Instead of utilising body-worn ECG electrodes, capacitive electrodes that can be placed inside clothing rather than clinging to the body with gel are recommended. The following recommendations are also made to improve the design prototype:

a) To conserve energy and extend battery life, ultra-low power systems may be constructed using low power wireless protocols.
b) Solar-powered ECG electrodes are recommended for usage in the future.
c) Compact electrodes with all necessary electronics must be used to eliminate the need for extra electronics to be carried.
d) For a much better assessment of CVD, there is a need to integrate the system with a GSM module, to allow for the transmission of ECG signals, heart rate, and SpO_2 patient data through mobile phones and the internet for remote and automated monitoring.

Conclusions

The research was carried out to develop a real time integrated electrocardiogram (ECG) and reflectance-based pulse oximetry system. The design and development of a heart rate monitoring tool that monitors the heart rate accurately, swiftly, and cheaply without the need of time-consuming and expensive clinical pulse detection equipment is given. It was successful in designing and building a prototype for a single channel, three-lead electrocardiograph that properly analysed differential potentials and produced the ECG recordings. The results demonstrate that the portable ECG correctly detects the electrode signal; however, a 50Hz filter is needed to ensure that power supply noise interference does not significantly impede the reading of the ECG signal in order to improve the system. On DSO138, graphic data from digital ECG data were finally created. Because of its compact size and simplicity of use, this portable ECG equipment may be used in villages, clinics, or homes. The findings section demonstrates how the designed pulse oximeter system provided heart rate and blood oxygen saturation measurements consistent with international devices. The device was designed to be simple, and to effectively reduce signal disruption using both antilog and digital signal processing techniques.

The device is able to ergonomically detect, filter, digitise, and display an ECG trace, heart rate and blood oxygen saturation of a user. After a process of designing, experimenting, testing, and data collecting, the author concludes that the ECG and

pulse oximeter system works properly according to the experimental results on several volunteers as the results were compared with standard international medical devices approved by the FDA. The device's minimum system circuit works properly as it controls and displays all parameters listed in the objectives of the research.

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