ISSN 0511-5728
The West Indian Journal of Engineering
Vol.42, No.1, July 2019, pp.65-71

Design and Development of a Cardiovascular Monitoring System

Solomon C. Nwaneri [a, Ψ], and Prince I. Ogbuji [b]

Department of Biomedical Engineering, College of Medicine, University of Lagos, Idi-Araba, P. M. B. 12003, Lagos, Nigeria
[a]Emails: snwaneri@unilag.edu.ng; snwaneri@yahoo.com
[b] Email: princepbt@yahoo.com

[Ψ] *Corresponding Author*

(Received 25 February 2019; Revised 12 June 2019; Accepted 21 June 2019)

Abstract: *Cardiovascular diseases are the most common causes of deaths globally. Continuous and regular monitoring of vital signs is necessary for patients suffering from cardiovascular diseases especially in low and middle income countries (LMIC), with limited facilities for diagnosis and monitoring of the cardiovascular system. In this paper, a low cost, non-invasive cardiovascular monitoring system was developed. The system was powered by a 12V battery and consists of a pulse rate sensor for recording pulse rate, heart monitor sensor for recording electrocardiogram, Arduino board (ATMega 2560), potentiometer, jumper connecting wires, 16×2 liquid crystal display monitor. The design includes modulation and demodulation sections that record signals from the measurand and transmit them to the doctor. The device was initially tested on ten subjects. Periodic heart beat was observed with mean ± standard deviation pulse rates obtained as 75.82 ± 1.09 BPM (beats per minute). Further comparison between the device and a standard blood pressure monitor on forty-five volunteers revealed a mean pulse rate of 76.44 ± 10.04 BPM and 77.84 ± 10.65 BPM for the proposed and standard device, respectively. The Wilcoxon-signed rank test results performed in SPSS gave a p-value of 0.118, showing that there was no statistically significant difference between the pulse rates observed in both devices. Standard Electrocardiograph (ECG) waveform for healthy subjects was obtained when the device was tested on healthy patients. Based on the test results, the device was shown to be effective for real-time monitoring of the cardiovascular system.*

Keywords: *Cardiovascular monitoring system, electrocardiogram, pulse rate, vital signs*

1. Introduction

Several diseases such as hypertension, myocardial infarction, atherosclerosis, arrhythmias and valvular heart disease, coagulopathies and stroke, are collectively referred to as cardiovascular diseases (CVDs) (Buttar et al., 2005). They are the most common causes of untimely deaths globally. According to the World Health Organisation (WHO), 17.9 million people die every year which constitutes 31% of all global deaths. Low and medium income countries (LMIC) account for over three quarters of deaths from CVDs (WHO, 2018). The prevalence and incidence of non-communicable diseases in LMIC is on the increase (Unwin, 2001; Vorster, 2002). Generally, CVDs are attributed to several risk factors such as age, sex, family history, tobacco smoking, physical activity, being overweight, diet, high blood pressure and diabetes (Heart and Stroke Foundation, 2018). Early diagnosis and regular monitoring are important and could minimise or delay deaths resulting from CVDs. Vital signs such as heart rate, blood pressure, blood oxygen saturation, body temperature and respiratory rate are often checked to determine the health conditions of a person especially if the patient is in danger (Dias and Cunha, 2018). Therefore, Electrocardiography is a vital tool for the prediction and diagnosis of CVDs (Xu et al., 2008).

Electrocardiograph (ECG) monitor is a non-invasive device that records the electrical activity of the heart muscle and displays it as an electrocardiogram (Goldberger, 2017). It provides indirect evidence of blood flow to the heart muscle and also evaluates arrhythmias and ischemic heart diseases (Raja, 2013; Ramya, 2013). ECG picks-up signals from the electrodes, processes and transmits them as FM signal at frequency ranging between 88 MHz and 108 MHz. The ECG signals are transmitted and received with low-power circuit of ≤ 10 mA. When the positions of ECG electrode (i.e., lead I, II, and III) on the body are changed, new ECG signals are recorded. ECG electrodes give the real-time ECG signal from the human body (Raja, 2013). In addition to the ECG, it is necessary to monitor other vital signs that affect the cardiovascular system such as the blood pressure and pulse rate. The pulse rate, also known as heart rate is the number of times the heart beats per minute which usually varies from one person to the order. It is a continuous time varying signal, with its variation providing indicators of current disease or warnings about imminent cardiac diseases (Acharya et al., 2004).

For a healthy adult, the heart rate is usually between 60-100 beats per minute (BPM). Resting heart rate is known to indicate the condition of the autonomic nervous systems as elevation in heart rate has been linked to increased risk of CVDs (Perret-Guillaume et al., 2009; Jouven et al., 2011). Heart rate variability (HRV), the variation over time of the interval between consecutive heartbeats often occurs even in healthy individuals (Achariya et al., 2006). A significant association between resting heart rate and mortality has also been suggested (Palatini and Julius, 2004). All-cause mortality and sudden and non-sudden death from acute myocardial infarction each increased gradually with elevated resting heart rate (Fox et al., 2007). Regular monitoring of the heart rate is necessary to prevent unexpected outcomes.

Hospitals can monitor outpatients at risk of unpredictable health conditions such as seizures, cardiac arrest, stroke and heart attack. There is an increased need in healthcare delivery to adopt proactive rather than reactive methods in early diagnosis, prevention, and long-term management of various health conditions (Anitha et al., 2017). The use of information and communications technology (ICT) combined with medical and engineering technologies enable healthcare researchers to enhance patient monitoring at home, outdoors and hospitals (Pandian et al., 2008). Texas Researchers showed that it is possible to transmit signals through wireless technology from 12-lead ECGs to hand-held computers (Pettis et al., 1999).

2. Literature Review

The ECG signal describes the electrical activity of the heart over time. It is recorded non-invasively with electrodes attached at the surface of the body. Traditionally, physicians use the ECG to gain insight on heart conditions, usually with complementary tests required in order to finalise a diagnosis.

Measurement of ECG is often based on Einthoven's law which states that *If Electrocardiograms are taken simultaneously with the three limb leads, at any given instant, the potential in lead II, is equal to the sum of the potentials in leads I and III*. It can otherwise be mathematically stated as:

$$II = I + III \quad (1)$$

Various devices have been previously designed to monitor the cardiovascular system. A heart rate monitoring system was developed using an embedded system based on a microcontroller for real-time analysis of ECG signals (Fezari et al., 2008). In 2008, a biotelemetry system for measuring heart rate and blood pressure from the human body was developed by Mohamed and Mounir (2008). A device capable of monitoring human temperature and pulse and showing abnormalities through SMS was developed by Selvarani (2011). Remote monitoring was achieved using Zig-Bee module which was incorporated to the device to transmit the heart beat and temperature through the programmed microcontroller to the computer. The computer collects the signals and sends them to SMS number through GSM modern (Selvarani, 2011).

Patient monitoring system was produced by Tagad and Matte (2013), which transmits the patient's information to the central receiving and remote communication unit via Zigbee. The information is then transmitted through the internet to the remote sensing unit where the information of the patient is stored in the database. The entire patient's information is passed into the database where the doctor can access the patient information from the computer. Anitha et al., (2017) designed a smart surveillance system to continuously measure and display the patient's ECG and temperature and send the results to the doctor's android phone. The device measures ECG by means of an infrared sensor and the temperatures measured using temperature sensors placed at the mouth and wrist of the patient. The microcontroller then reads the data from the sensors, displays the results and communicates it to the web server automatically.

Sopic et al., (2018) developed a real-time event-driven classification technique for early detection and prevention of myocardial infarction on wearable systems using a hierarchical classifier. By analysing the computational complexity and energy efficiency of the developed classifier, it was found that the scheme reduced energy efficiency by 2.6. Forooghifar et al. (2018) proposed self-aware wearable systems capable of monitoring their own performance in epileptic seizure detection as an approach to reduce energy consumption of wearable systems. A toilet seat-based cardiovascular monitoring system was proposed by Conn et al. (2019). The cardiovascular system was capable of hospital grade measurement of blood pressure, stroke volume and peripheral blood oxygenation. Conn et al., (2019) compared the toilet seat-based estimates of blood pressure and peripheral blood oxygenation to a hospital-grade vital signs monitor for 18 subjects over an 8-week period. The stroke volume was validated on 38 normative subjects and 111 subjects undergoing a standard echocardiogram at a hospital clinic for any underlying condition, including heart failure.

In LMIC, the incidence of cardiovascular diseases is on the increase (Gaziano et al., 2010). Hence, there is need to develop an inexpensive device which is affordable to a large segment of the population. The conventional electrocardiogram is bulky, expensive and prone to mechanical failure. This research focuses on the development of a portable inexpensive and simple cardiovascular monitoring system for hospitals capable of real-time monitoring of the ECG and heart rate of their patients with heart diseases. Primary care centers in most rural areas in LMIC need a simple battery powered device for monitoring the heart since poor infrastructure and limited or non-available electricity supply is a major problem in those communities.

3. Materials and Methods

3.1 Materials

The major materials used in the design and construction of the device include a pulse rate sensor, a heart monitor sensor, an Arduino Mega 2560 board, a potentiometer, jumper and connecting wires, USB cable, 16 × 2 Liquid Crystal Display (LCD) Module. The system monitors a patient's cardiovascular system, using different sensors connected to Arduino Mega 2560 board.

3.1.1 Pulse Sensor

Pulse rate sensor is an open-source and plug-and-play heart-rate sensor for Arduino that measures human heart rate (beats per minute). A velcro tape is used to position the LED (light-emitting diode) on human finger to avoid noise from the surroundings. The pulse rate sensor pins were connected to the microcontroller Arduino board as follows, the 'yellow' terminal is connected to analogue input pin of the arduino, 'orange' is connected to 5V, while 'red' is connected to ground (earth). After programming and uploading, the sensor passed when it was placed on human finger.

3.1.2 Heart Monitor (AD8232)

AD8232 Heart monitor is a one lead ECG sensor used for ECG heart rate monitoring. The AD8232 single lead heart rate monitor acts as an operational amplifier to help obtain a clear signal from the PR and QT intervals. Some of the advantages of this board include its ability to detect, amplify and filter small Bio-potential signals (Sparkfun, 2018).

2.1.3 Arduino MEGA 2560

Arduino Mega 2560 is a microcontroller board that is based on ATmega2560. The Arduino board reads the value of the sensors and sends the processed information to the LCD monitor and PC Serial Monitor. It has 54 digital input/output pins, comprising 15 pins for PWM outputs, 16 pins for analog inputs, 16 pins for crystal oscillator. It can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The ATmega2560 provides four hardware UARTs for Transistor-Transistor Logic, TTL (5V) serial communication, it also supports i2C (TWI) and SPI (Serial Peripheral Interface) communication (Arduino, 2019).

2.1.4 Potentiometer

Potentiometer produces variable resistance used to control the amount of current that enters the LCD. It is made of a simple knob that can read into the Arduino board as an analog value. In this device, it controls the 16×2 LCD which displays BPM values from pulse rate sensor.

2.1.5 Liquid Crystal Display Module

The 16×2 LCD displays the pulse rate. It is a form of visual indicator that displays 16 characters in each row and there are two rows in 5×7-pixel matrix. It can display any character with ASCII values ranging from 0 to 255. There are two registers in this LCD module; command and data. The command register stores the command instructions given to the LCD to perform a predefined task (like initialising it, clearing its screen, setting the cursor position, and controlling display, etc.). The data register stores the data to be displayed on the LCD. The data is the ASCII (American Standard Code for Information Interchange) value of the character to be displayed on the LCD.

3.2 Device Implementation

The functional block diagram of the device is shown in Figure 1. The device was powered by a 12V battery. AD8232 heart monitor, comprising ECG electrodes sensor placed on the patient's body as indicated in Figure 2, detects the electrical activity of the heart and transmits the signal to the Arduino board. Similarly, an Arduino compatible pulse rate sensor detects the pulse rate and transmits it to the Arduino board.

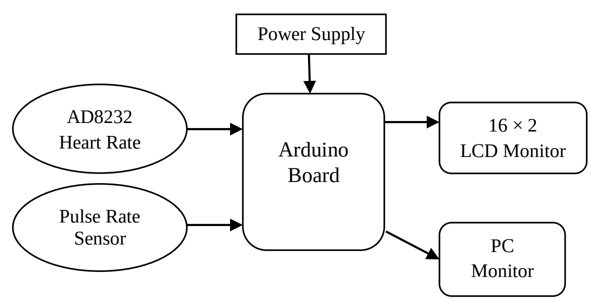

Figure 1. Functional Block Diagram of the Device

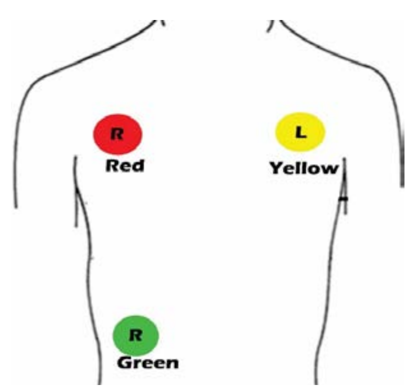

Figure 2. The placement of AD8232 ECG Sensor on human body

Table 1. Bill of Quantities

Description	Unit Cost ($)	Quantity	Total Cost (US$)
AD8232 ECG/Heart Rate Monitor	15.65	1	15.65
Arduino Mega 2560	22.00	1	22.00
Pulse Rate Sensor-Arduino Compatible	11.10	1	11.10
Breadboard	1.38	1	1.38
Potentiometer	0.50	1	0.50
PVC Pipe Junction Box	2.70	1	2.70
Jumper (connecting wire)	12.10	1 pack	12.10
I2C LCD Module + 16x2 LCD	7.12	1	7.12
Total			**72.55**

The Arduino microcontroller board receives the input signals from both sensors, first converts the analogue signals to digital through its inbuilt analogue to digital converter, and performs signal filtering to eliminate noise and amplification (Jeon et al., 2013). It then interprets and transmits the signal to the LCD and PC monitors which display the results. For the ECG, the results are displayed in a waveform, while the pulse rate only shows the numerical value in BPM. A potentiometer which is connected to the 16×2 LCD provides variable resistance by controlling the amount of current that enters the LCD.

The total cost for producing the prototype was US$72.55 as shown in the bill of quantities in Table 1. This makes it cheaper than equivalent products in the market sold at an average of US$300.

4. Results and Discussion

A cardiovascular monitoring system to monitor the electrical activity of the heart and the heart rate was developed in this study as shown in Figure 3. The device was developed with a low power 12V dc supply which is associated with minimal or insignificant risk to the user.

Figure 3. Cardiovascular Remote Monitoring System

The device was tested on forty five subjects with the results for each test displayed on the LCD screen of the device and Arduino 1.8.9 IDE Serial plotter. Graphical results of the heart ECG and pulse rates obtained are shown in Figures 4 and 5.

The horizontal axis of the ECG represents time and the vertical axis represents the amplitude of the voltage. The time scale is 25 mm which is equal to 1 second (or 1mm = 0.04 seconds on the graph). Amplitude units are millivolts (mV) and 1 mV on the graph equal to 10mm high (Israel et al., 2005).

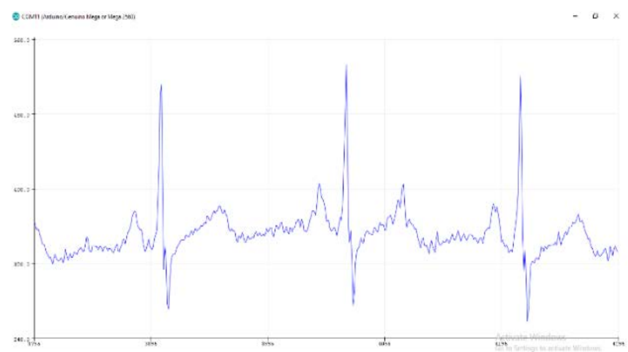

Figure 4. Heart ECG (Serial plotted)

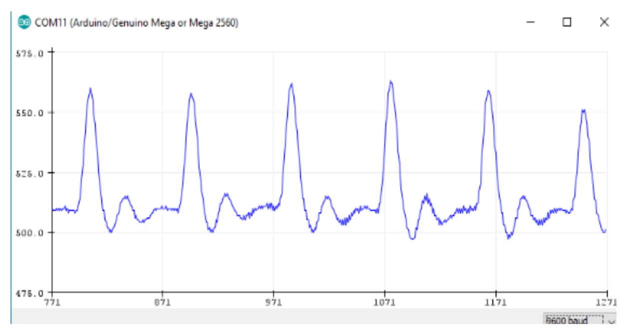

Figure 5. Pulse Rate (BPM) Serial plotted graph

The results reveal that the heartbeat is periodic. If the heart rate is 60 BPM or 1 beat per second, the period is 1 second or 1,000 milliseconds. Choosing R-wave from QRS complex, it was observed that R-wave is 25mV high for the total of 40ms and R-wave can be modeled by using polynomial and units of time in milliseconds. ECG signal determines the number of heart beats per minute. The principal features of an ECG signal shown by letters P, Q, R, S, and T in a normal hearts waveform start with P-wave, then QRS complex to T-wave. P-Wave is initiated by depolarisation of the atrial muscles which is related to their contraction. The QRS-wave complex generated by depolarisation of the ventricles is connected to their contraction. T-wave is as a result of currents flow during the repolarisation of the ventricles. A normal cardiac cycle of an individual at rest with all waveforms spans 0.8 seconds (Ackora-Prah et al., 2013).

To determine heart rate variability, the device was tested on one of the researchers for seventeen times with the mean, median and mode obtained as 71.06 ± 0.899, 71.00 and 71.00 BPM, respectively. Heart rate variability was normal. It is within the range of a healthy adult at rest using a standard heart beat monitor (Nanchen et al., 2013). Figure 6 shows the variability in pulse rate.

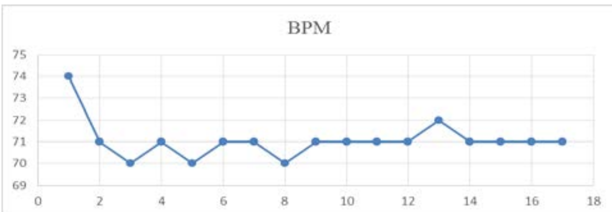

Figure 6. Variability in Pulse rate (BPM)

Pulse rate of forty-five (45) volunteers who willingly participated in the research from the Nigerian Institute of Medical Research (NIMR), Lagos and the Yaba College of Technology were examined using this device and a standard blood pressure monitor, MAS200 BPM. Results are as shown in Tables 2 and 3, and Figures 7 and 8.

Table 2. Descriptive Statistical Values for Pulse Rates (BPM) using this device

		Age	Pulse Rate
Mean		25.82	76.44
Std. Error of Mean		1.09	1.50
Median		24.00	78.00
Std. Deviation		7.29	10.04
Minimum		17.00	56.00
Maximum		48.00	97.00
Percentiles:	25	21.00	69.00
	50	24.00	78.00
	75	29.00	84.00
Sample Size = 45			

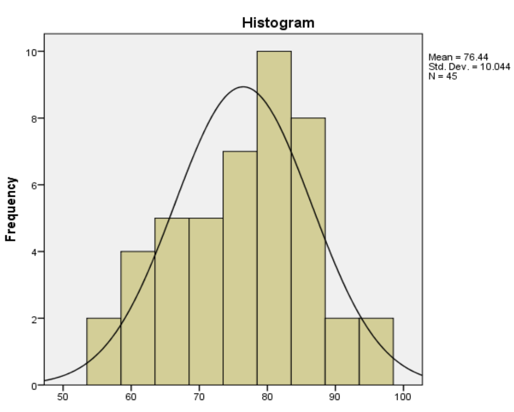

Figure 7. Histogram of Pulse Rate (BPM) using this device

Table 3. Descriptive Statistical Values for Pulse Rates (BPM) using MAS200 Blood Pressure

	Age	Pulse Rate
Mean	26.82	77.84
Std. Error of Mean	1.09	1.588
Std. Deviation	7.29	10.654
Minimum	17.00	56.00
Maximum	48.00	100.00
Sample Size = 45		

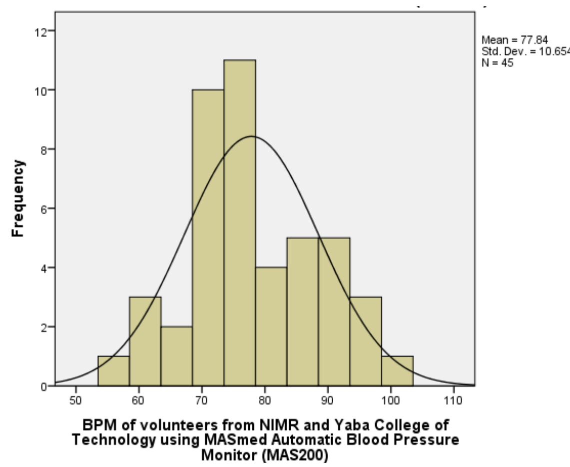

Figure 8. Histogram of Pulse Rate (BPM) using MAS200

However, a p-value of 0.114 at 95% confidence interval showed that there are no statistically significant differences between the heart rate measurements from both devices. The device could be very useful for monitoring heart rates both at home and in the hospital since the patient is exposed to only minimal risk. If this device is commercialised and made readily available to patients especially in rural areas and clinics it has the potential to enhance the monitoring of the cardiovascular system and minimise the incidence of complications from cardiovascular diseases.

5. Conclusion

A cardiovascular monitoring system was developed in this study. The proposed device was tested on various subjects. It is very affordable and shown to be effective in monitoring the heart rate and electrical activity of the heart. It could be useful in a resource poor setting with limited diagnostic medical devices. The device is non-invasive and allows patients to maintain independence, prevent complications, and minimise healthcare costs.

References:

Acharya, U.R., Joseph, K.P., Kannathal, N., Lim, C.M., and Suri, J.S. (2006), “Heart rate variability: A review”, *Medical and Biological Engineering and Computing*, Vol.44, No.12, pp. 1031-1051.

Ackora-Prah, J., Aidoo, A.Y., and Gyamfi, K.B. (2013), “An artificial ECG signal generating function in MATLAB”, *Applied Mathematical Sciences*, Vol.7, No.54, pp.2675-2686

Anitha, K., Rajendran, R., and Mathiarasan, P. (2017), “Smart health surveillance with automated database using android mobile device”, *Brazilian Archives of Biology and Technology*, Vol. 60, pp.1-14.

Arteta, C. (2012), “Low-cost blood pressure monitor device for developing countries”, *Lecture Notes*, The Institute For Computer Sciences, Social-Informatics and Telecommunications Engineering, 83 LNICST, pp.335-342.

Arduino (2019), “Arduino Mega 2560”, Available from: https://store.arduino.cc/usa/mega-2560-r3. [Last accessed on January 29, 2019]

Buttar, H.S., Timao, L., and Ravi, N. (2005), “Prevention of cardiovascular diseases: Role of exercise, dietary interventions, obesity and smoking cessation”, *Experimental Clinical Cardiology*, Vol.10, No.4, pp.229-249.

Conn, N.J., Schwarz, K.O., and Borkholder, D.A. (2019), “In-home cardiovascular monitoring system for heart failure: Comparative Study”, *JMIR mHealth Uhealth*, Vol.7, No.1, pp. e12419.

Dias, D., and Cunha, J.P.S. (2018), “Wearable health devices: Vital sign monitoring, systems and technologies”, *Sensors (Basel)*, Vol.18, Available from: https://www.mdpi.com/1424-8220/18/8/2414/htm.

Fezari, M. Bousbia-Salah, M. Bedda, M. (2008), “Microcontroller based heart rate monitor”, *International Arab Journal of Information Technology*, Vol. 5, No.4; pp.153-157.

Forooghifar, F. Aminifar, A. and Atienza, D. (2018), “Self-aware wearable systems in epileptic seizure detection”, *Proceedings of the 21st Euromicro Conference on Digital System Design (DSD)*. IEEE, Prague, Czech Republic, August, available from https://ieeexplore.ieee.org/document/8491849.

Fox, K., Borer, J.S., Camm A.J., Danchin N., and et al. (2007), “Resting heart rate in cardiovascular disease”, *Journal of American College of Cardiology*, Vol.50, No. 9, pp.823- 830.

Gaziano, T.A., Bitton, A., Anand, S., Abrahams-Gessel. S., and Murphy, A. (2010), “Growing epidemic of coronary heart disease in low- and middle-income countries”, *Current Problems in Cardiology*, Vol. 35, No.2, pp.72-115.

Goldberger, A.L., Goldberger, Z.E., and Shvilkin, A. (2017), *Goldberger's Clinical Electrocardiography: A Simplified Approach*, 9th Edition, Elsevier, Philadelphia.

HSF (2018), “The growing burden of heart disease and stroke”, Heart and Stroke Foundation, Available from: http://www.cvdinfobase.ca/cvdbook/CVD_En03.pdf/. [Last accessed on October 12 2018).

Israel, S.A. Irvine, J.M. Cheng, A. Wiederhold, M.D. Wiederhold, B.K. (2005), “ECG to Identify Individuals”, *Pattern Recognition*, Vol.38, pp.133 -142.

Jeon, B., Lee, J., and Chor, J. (2013), “Design and implementation of wearable ECG system”, *International Journal of Smart Home*, Vol.7, No.2, pp.61- 69.

Jouven, X., Escolano, S., Celermajer, D., Empana, J.P., Bingham, A., Hermine, O., and et al. (2011), “Heart rate and risk of cancer death in health men”, *PLoS ONE*, Vol.6, No.8, pp.e21310.

Mohamed, Fezari and Mounir, Bousbia-Salah (2008), “Microcontroller based heart rate monitor”, *International Arab Journal of Information Technology*, Vol.5, No.4, October, pp.

Nanchen, D., Leening, M.J., Locatelli, I., Cornuz, J., Kors, J.A., Heeringa, J., Deckers, J.W., Hofman, A., Franco, O.H., Stricker, B.H., Witteman, J.C., and Dehghan, A. (2013), “Resting heart rate and the risk of heart failure in healthy adults: The Rotterdam Study”, *Circulation: Heart failure*, Vol.6, No.3, pp.403- 410.

Palatini, P., and Julius, S. (2004), “Elevated heart rate: a major risk factor for cardiovascular disease”, *Clinical and Experimental Hypertension*, Vol.26, pp.637- 644.

Pandian, P.S. (2008), “Smart vest: Wearable multi-parameter remote physiological monitoring System”, *Medical Engineering and Physics*, Vol.30, No.4, pp.466-477.

Perret-Guillaume, C., Jolly, L., and Benetos, A. (2009), “Heart rate as a risk factor for cardiovascular disease”, *Progress in Cardiovascular Disease Journal*, Vol.52, No.1, pp.6-10.

Pettis, K.S., Savona, M.R., and Leibrandt, P.N. (1999), “Evaluation of the efficacy of hand-held computer screens for cardiologist interpretations of 12-lead electrocardiograms”, *American Heart Journal*, Vol.138, No.4, pp.765-770.

Raja, D.S. (2013) “Wireless transmission of real time electrocardiogram (ECG) signals through radio frequency (RF) waves”, *International Journal of advanced Research in Electrical/Electronics and Instrumentation Engineering*, Vol. 2, No. 2, No. 2, pp. 793- 798.Ramya, V. (2013), “Remote monitoring and logging system using Zigbe”, *Journal of Computer Application*, Vol.64, No.13, pp.49- 55.

Reule, S., and Drawz, P. (2012), “Heart rate and blood pressure: Any possible implications for management of hypertension?” *Current Hypertension Reports*, Vol.14, No.6, pp.478-484.

Selvarani, S.J. (2011), “Online health monitoring system using Zig-bee”, *International Journal of Computer Science*, Vol.3, No.4, pp.1578 -1583.

Sopic, D., Aminifar, A., and Aminifar, A. (2018), “Real-time event-driven classification technique for early detection and prevention of myocardial infarction on wearable systems”, *IEEE Transactions on Biomedical Circuits and Systems*, Vol.99, pp.1-11.

Tagad, A.B., and Matte, P.N. (2013), “Design and development of a wireless remote POC patient monitoring system using Zigbee”, *International Journal of Emerging Technology and Advanced Engineering*, Vol.3, No.12, pp.435-439.

Sparfun (2018), *Sparkfun Single Lead Heart Rate Monitor – AD8232*, Available from: https://www.sparkfun.com/products/12650. [Last accessed on 2018 Nov 28].

Xu, P.J., Zhang, H., and Tao, X.M. (2008), “Textile-structured electrodes for electrocardiogram”, *Textile Progress*, Vol.40, pp.183-213.

Unwin, N. (2001), “Non-communicable disease and priorities for health policy in sub-Saharan Africa”, *Health Policy Plan*, Vol.16, pp.351-352.

Vorster, H.H. (2002), “The emergence of cardiovascular disease during urbanisation of Africans”, *Public Health Nutrition*, Vol. 5, pp. 239–243.

WHO (2018), *Cardiovascular Disease*, World Health Organisation, Available from: https://www.who.int/cardiovascular_diseases/en/ [Last accessed on 2018 November 27].

Authors’ Biographical Notes:

Solomon C. Nwaneri *is a Lecturer at the Department of Biomedical Engineering, The University of Lagos Nigeria. He obtained his B. Eng. degree in Electrical/Electronic Engineering in 2001 and a Master’s degree in Project Management Technology from in 2009, both from The Federal University of Technology Owerri (FUTO), Nigeria. He also obtained another Master’s degree in Electrical/Electronic Engineering (Electronic option) from The University of Lagos Nigeria in 2014 and a PhD in Industrial/Production Engineering in 2017 from The University of Ibadan, Nigeria. His Research interests are in biomedical devices, healthcare optimisation and analytics.*

Prince I. Ogbuji *is a Biomedical Engineer in the Department of Works and Maintenance, at Nigerian Institute of Medical Research, Yaba, Lagos, Nigeria. He obtained his National Diploma in Science Laboratory Technology in 2006 and Bachelor of Technology in Biomedical Technology in 2011, and both from The Federal University of Technology Owerri (FUTO), Nigeria. He also obtained a Master’s degree in Biomedical Engineering*

from The University of Lagos, Nigeria in 2018. His Research interests are in biomedical engineering, medical and in vitro diagnostics devices. ■