

Remote Heartbeat Monitoring System for Cardiovascular Patients

Toyeeb A. Musliudeen
Department of
Telecommunication Science University
of Ilorin
musliudeentoyeeb@gmail.com

Lukman A. Olowoyin
Department of
Telecommunication Science University
of Ilorin
lolawoyin@unilorin.edu.ng

Abdulkarim A. Oloyede
Department of Electronics, University
of York, UK
aao500@york.ac.uk

Timothy K. Oyun
Department of
Telecommunication Science University
of Ilorin

Nasir Faruk
Department of
Telecommunication Science University
of Ilorin
Faruk.n@unilorin.edu.ng

Ibraheem Katibi
Cardiology Unit, Department of
Medicine
University of Ilorin
iakatibi@unilorin.edu.ng

Abstract— The rise in Cardiovascular disease (CVD) cases is alarming, as it's become the world's major disease contributing to almost 50% of noncommunicable disease. The need to have real time access of the patient's heart condition (heartbeat) is necessary in proper management and treatment of CVDs. However, the lack of manpower and adequate funding hinder the deployment of heart beat monitors in considerable number of hospitals in developing countries. In this paper, we present design and implementation of energy efficient and cost-effective remote heartbeat monitoring system. The implementation consists of pulse sensor, Arduino UNO, HC-05 Bluetooth module and 9v battery. The ATmega328 microprocessor of the Arduino is programmed in C language with the use of the library function "Pulse Sensor Playground" of the Arduino, while the end terminal application is programmed with java via processing. A front end application was developed and used to display the pulse data. The device constructed operates smoothly, based on the sampled BPM data collected from 5 adults. The design is quite efficient as it successfully connects the pulse sensor remotely to the frontend application. It also relays the BPM value to the terminal device in real time.

Keywords—heartbeat monitor, Cardiovascular, energy efficiency Arduino, Bluetooth

I. INTRODUCTION

Cardiovascular disease (CVD) is a condition involving the blood vessels, either narrowing or complete blockage of the blood vessels, resulting to heart attack. Some examples of this disease include the heart failure, heart attack, coronary artery diseases, stroke and many others [1].

The global rise in CVDs cases has become the topic issue and burden as its currently the world's major disease contributing to almost 50% of non-communicable disease [2]. This has surpasses the communicable diseases. The global death as the result of CVDs currently stood at 17.3 million deaths per year, this number however, is expected to grow even higher by the year 2030 [2].

Hence, detecting this disease is essential and one of early step is to examine for irregular heartbeat pattern in a patient. The rate at which the heart beats could be used as a basis for detecting the condition of the heart of a patient. The heartrate (HR) varies in accordance to the age, activity and the condition of a person. The HR for a healthy adult, defined as

the HR at rest is the number of occurrence of the beat of the heart in the sitting condition, when lying down or when the nerve is calm. This is set within the range of 60 to 100 beats per minute (b/m) [3]. However, the HR of an athlete and an active adult is slower than that of a resting or stationary person [4]. The normal HR for a baby (less than one year of age) is higher and this is expected to be around 120 to 160 bpm and that of an healthy child is expected to be around 75 to 110 bpm [5].

Over the years, there have been different methods of measuring heartbeat. However as technology advances, the methods involved is also advancing. The conventional manual method of taking the heart pulse has advanced into electronic methods [6]. Two of the most common types of the electronic methods are the electrical method (electrocardiography) and the optical method (photo plethysmography). The electrical method uses the voltage extracted from placing a strap of electrode pads on the body, while that of the optical method uses light as its source of data [7]. The optical method of the pulse sensor involves the process of placing the fingertip between the infrared transmitter and a photodiode sensor. As blood flows through the vein, it absorbs the infrared light which is in turn captured by the photodiode sensor. Afterwards, the intensity of the reflected light captured by the photodiode sensor (LDR) yields the blood pulse value [8]. The pulse value is then further displayed via a display terminal for access by a cardiologist or medical practitioner.

The need to have real time access of the patient's heart condition (heart beat) is necessary in proper management and treatment of CVD. Heart beat monitoring systems is commonly used to measure the heartbeat of patients. However, lack of manpower and adequate funding hinder the deployment of the devices in considerable number of hospitals in developing countries. Moreover, power supply is another big issue to sustain the running of these devices within the time span needed to monitor patients with CVDs. Furthermore, the economic pressure and realities has pushed most of the healthcare industries to seek for new and cost effective paradigms that could provide health care service to people. Therefore in this paper, a user friendly, portable, cost and energy efficient heart beat monitoring system that could be used to remotely (via wireless medium), access the beat rates or HR of patients with CVD is developed. The device allows for remote monitoring of a patient which is often required as the doctor to patient ratio in Africa can be as low

as 1:50000 [9]. The device also provides a short range wireless technology for sending the captured HR to a remote terminal. The remote terminal would be able to display the HR of different patients from time to time.

II. RELATED WORKS

There are two major types of devices used in monitoring the heart rate. These include the electrical methods which require placing a large strap of device on the body while the optical method doesn't require anything of such and can be effectively used as compared to the electrical method [10]. The development of low cost heart rate measuring device can be achieved through the use of optical technology where LDR and LED are used in sensing the pulses [11]. The amplifier circuit amplifies the pulse signal, and then filters it through a band pass filter. The microcontroller receives the amplified and filtered pulse signal, and then processes the analog signal. Afterwards, it then counts the HR and displays it on the LCD display [12], [13].

In [14], optical technology was employed to design a microcontroller-based HR monitor via fingertip sensor was presented. Optical technology was employed by the device in detecting blood that flows through the fingers, and in the process offers great advantage of handiness, usability and portability over the tape-based recording system. The Discrete Fourier Transform was applied in analyzing the electrocardiography (ECG) signals in order to derive the HR measurement. In the research work, the performance of the HR monitoring device was taken in comparison with the ECG signal represented on an oscilloscope and the manual pulse measurement of the heartbeat.

In [15], a compliance tracking mechanism (called CHF Tel-Assurance) was implemented [15]. Patients were monitored with the aid of technology and were reviewed on a weekly basis by a multidisciplinary team. Some of the team members from the cardiac rehabilitation telemetry, and home care research units. The goals of the team were to make provision for an improved patient result, hospitalization, and readmission rates. The core approach was to allow patients to be the co-handler of how their heart system behaves via user education on usable technology.

The core approach in [16] was to allow patients to be the co-handler of how their heart system behaves via user education on usable technology. In this article, seventy-four (74) heart failure patients were enrolled in the ECG monitoring and telephone follow-up program. In response, patients are capable of sending their respective ECG data from their mobile telephone to a remote receiving terminal where the data could be accessed by a heart care professional. The patients were evaluated and responded to, based on the ECG data that the patient must have sent to the remote consultant.

Bodmas et al [17] tried to establish the feasibility and potency of remote monitoring and management of the chronic heart failure. Patients were assessed by tele-monitoring for HR, blood pressure, weight and arterial saturation of oxygen. Patient's satisfaction, safety and quality of life based on the implementation of these approaches were evaluated for humanistic outcome.

Also, According to S.A Moraru, Szakacs, and L. perniu in [18], the proposition of the authors was based on having a device that is wearable on the patient's body which will

allow free mobility of the patient while his / her health parameters being monitored. A wireless sensor is to be used in monitoring the health parameters such as the HR, and connectivity is made to mobile application via bluetooth.

In [19], the authors proposed a system for people in rural areas due to their inaccessibility to doctors and other medical practitioners that would monitor their health parameters (such as the heart rate). It was as well proposed in [19], a bi-analysis hierarchical method. The first layer been an integration with android phone that stores data at SQLite, analyzes the data and then send a text based emergency short message to the health practitioners. After receiving the message, the medical practitioner then analyzes the data received.

III. DESIGN AND IMPLEMENTATION

The components used in carrying out the full implementation of this work are presented. The components can be sub-divided into two: Hardware components (Pulse sensor, Arduino UNO and Bluetooth module) and Software components (Arduino IDE (Integrated development Environment) and Processing).

A. Pulse Sensor

This is an Arduino based plug-and-play sensor for taking the rate at which the heart beats. It is majorly used by developers, athletes, students, for easy incorporation of real time data of the amplifier and noise cancellation circuits which aid its ability to produce a reliable pulse reading easily and quickly [20] [21]. A picture of the front and back view of this device is shown in figure 1.

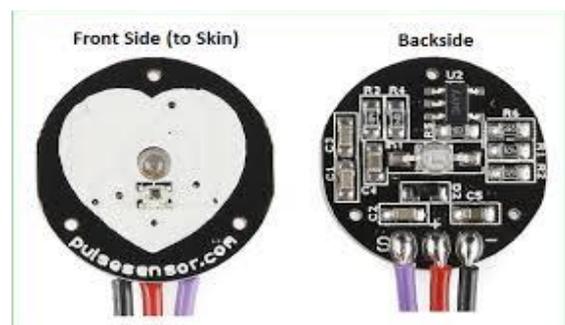


Fig 1. Front view and back view diagram of a pulse sensor [27]

B. Arduino UNO

The Arduino UNO is an ATmega328P integrated circuit open source microcontroller board. It has seven power pin, and Eighteen (18) input / output digital pins of which Twelve (12) are dedicated to digital PWM and Six (6) analogue input. It also has a reset button, USB connector, and a power jack as shown in Fig 2. The components that make up the controller are designed in such a way to perform the functions of a microcontroller. All that is needed is to connect it to a power source (such as a 3V or 5V battery or to computer via USB cable) to start the device. The Arduino UNO has been embedded with an inbuilt boot loader to upload a new program to the board of the Arduino. However, the boot loader can be bypassed thereby controlling the microcontroller with the use of the In-Circuit Signal Programming (ICSP) header [22, 23]

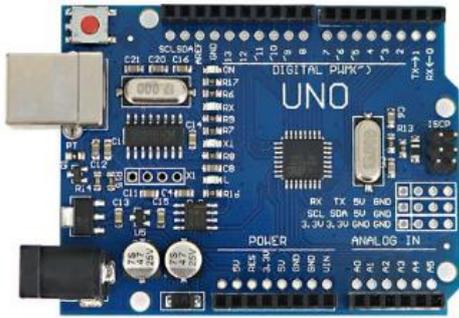


Fig 2 Arduino UNO with ATmega328p Microprocessor [28]

C. Bluetooth Module (HC-05)

Bluetooth module was used to interface with an Arduino board in order to transmit the data from the Arduino board to a Bluetooth-enabled terminal such as a PC [24]. The Bluetooth module used in this work is Bluetooth module HC-05 which can either be set to master or slave. The module has Seven (7) pins, namely; KEY, VCC, GND, TXD, RXD and STATE as shown in figure 3. These are ONLY Six pins and not Seven. Among all the just mentioned pins, the needed ones for this project are; the VCC which the voltage source from the Arduino is connected to, the GND that is connected to the Arduino ground pin, the RXD that receives data from the Arduino transmitting serial, and the TXD which transmits the received serial data from the Arduino to the end terminal [25].



Fig 3. Front and Back view of HC-05 Bluetooth module [29]

D. Arduino IDE

The Arduino integrated development environment is an environment in which an Arduino board can be programmed. A written program or code is called SKETCH [23]. In this work, the Arduino IDE is used as an environment in which the Arduino UNO program is written, compiled and uploaded on the Arduino board as depicted in figure 4.



Fig 4. Arduino IDE

E. Processing

Processing is an open source developing agent tool for writing an application program which in turn can be used in the same or other computer [26]. Its usefulness in this project is when the computer is needed to communicate with the Arduino. In this project, the processing software is used to program java based computer application, named remote heart rate monitor, to display the reading and pulse wave of the sensor on the computer. What it does is that it creates an environment that accepts data from the Arduino via the Bluetooth module and displays it on the application created from this processing environment.

IV. IMPLEMENTATION AND RESULTS

This work is implemented using cost effective and energy efficient method. The schematic design used for the implementation of the work is shown in fig. 5 while the flow chart is shown in figure 6. The simplicity of the method can be seen from the flow and block diagram.

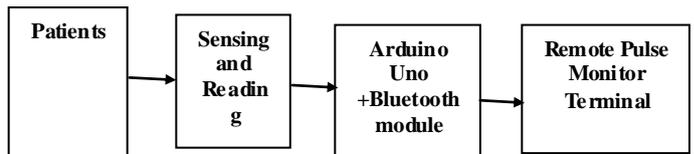


Fig 5: Block Diagram of Design

The project was first implemented using a breadboard to be able to determine any problem with any of the components and while putting the components together. As shown in figure 8, a set of LEDs are connected on the circuit board. A resistor of 200Ω is used in regulating the input voltage of the LED to prevent it from burning because of high input voltage to the LED.

Furthermore, the schematic block diagram is also shown in figure 7. It can be seen from this diagram that the patient's pulse rate is measured, analyzed and then wirelessly relayed to a distance-dependent remote terminal.

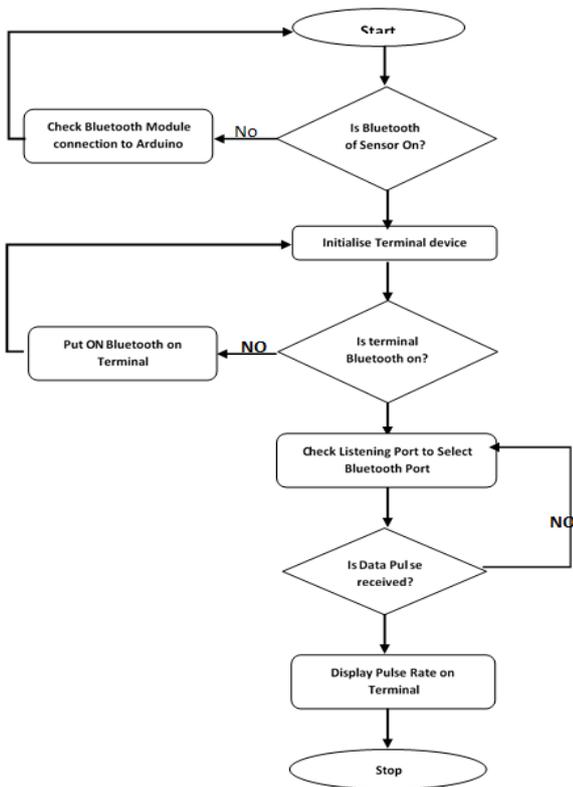


Fig 6: Flow chat for Implementation

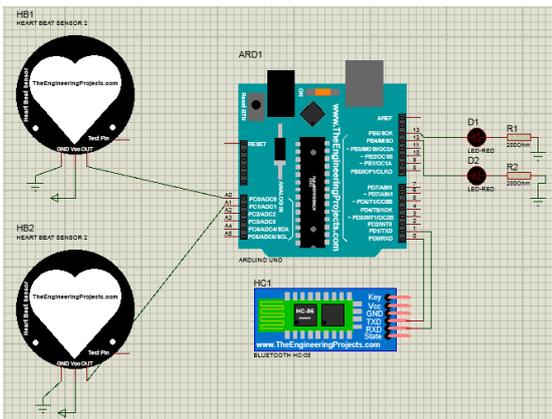


Fig 7: Block diagram of the remote heart rate monitoring system.

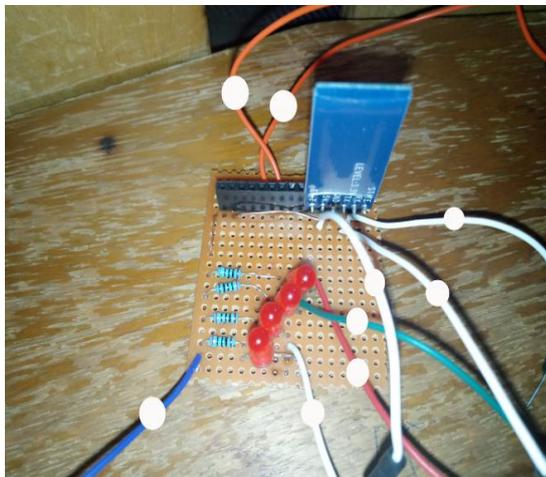


Fig 8 Project implementation on Printed Circuit Board (PCB).

The value of the resistor was determined using the equation below

$$R = \frac{V_s - V_f}{I_f} \quad 1.0$$

Where;

R is the value of the unknown resistor

V_s is the supply voltage power used in powering the circuit in our case the value is $5v$ as this is the output voltage from the Arduino

V_f is the forward voltage required to power the LED in our case the value is $2v$

I_f is the forward current required for the LED to operate and in our case, this is $15mA$

The work was implemented by connecting the anode (+ve part) of the LED to the Arduino PIN while the cathode (-ve part) is grounded on the circuit board. The female pin connector is also attached to the circuit board which contains the ground port, voltage port, analog port and Bluetooth module port. The prototype produced is as shown in Fig 9 below with a small electrical junction box which contains all the components (Arduino UNO, circuit board and a 9V DC battery). To test the device, there is need to ensure that the Bluetooth module HC-05 is paired with the end terminal. The module must then be attached to a specific computer port on the end terminal device as shown in Figure 10 below;

After attaching a port to the HC-05 Bluetooth module, the HRM application can then be launched as shown in Fig 11.



Fig 9: Prototype remote Heart rate Monitor System

It can be seen at Fig 10 that once the application is launched, all available ports on the terminal device are shown. Once the appropriate computer port is selected, the pulse data will be received on the selected port. On the terminal device where this project is implemented, the HC-05 Bluetooth module was attached to computer port 21 for

the recipient of the pulse data in real time as shown in Fig 12 and 13.

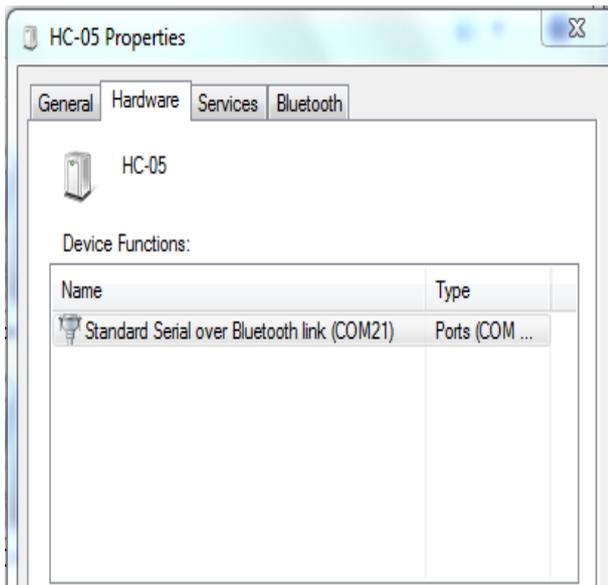


Fig 10: Port allocation to HC-05 Bluetooth module

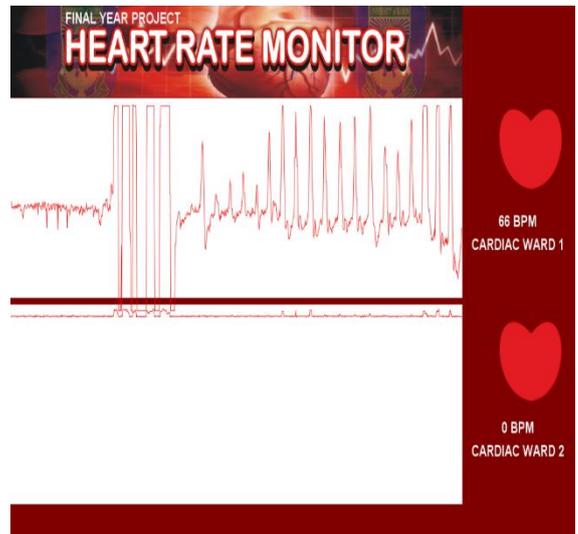


Fig 13: Pulse sensor taken for one person

The terminal application displays the pulse rate in bit per minute (BPM) and the pattern of individual heartbeat.

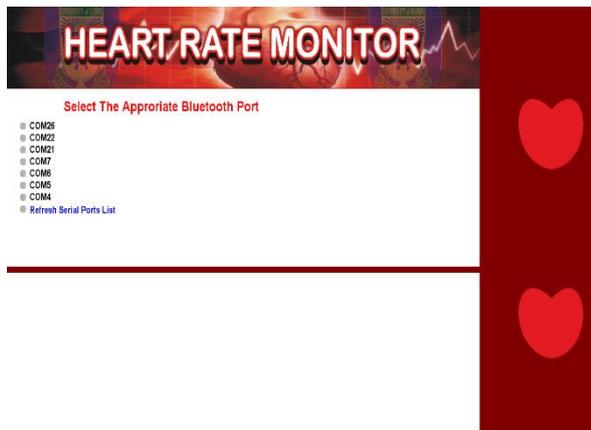


Fig 11: Port selection on the terminal device

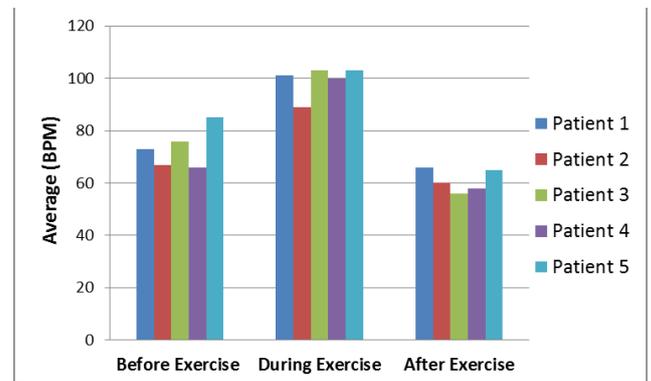


Fig 14. Average BPM

TABLE 1: HEART RATE VARIABILITY OF 5 PATIENT; BEFORE, DURING AND AFTER EXERCISE

Patient ID	before Excersie (BPM)			During Excersie (BPM)			After Excersie (BPM)		
	1	2	Avg	1	2	Avg	1	2	Avg
Patient 1	72	74	73	94	108	101	67	64	66
Patient 2	69	64	67	80	98	89	62	58	60
Patient 3	74	77	76	100	105	103	58	54	56
Patient 4	65	66	66	95	105	100	60	55	58
Patient 5	80	89	85	98	108	103	63	66	65

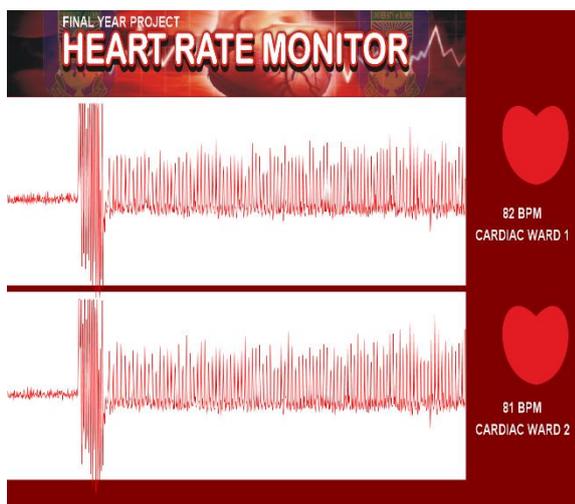


Fig 12: Pulse sensor taken for two people

The HR monitor device successfully connects remotely to the front-end computer-based application via a short-range Bluetooth connection. The front-end application displays the BPM value of the individual that has the pulse sensor placed on his or her body, majorly on the index finger. It was observed that the front-end application displays high BPM value, usually above 150, on startup. Accurate BPM is recorded when the monitored individual is fully settled and calm for some minutes. Furthermore, when the accurate BPM value is displayed, just as that in the Figure Fig what, the value mostly varies with difference of five. That is, when the displayed BPM value is 83, it might keep showing values

from 83 to 88. It must also be noted that the configured band rate (rate of data transmission) is 9,600 at both heart rate monitor and the front-end application, based on the HC-05 Bluetooth recommendation.

Furthermore, for validation, the HR of five different adults were sampled, before, during and after a set of exercise. The results obtained are shown in Table 1. In Table 1, the heart rate obtained are all within the normal range expected for healthy people, even though, the device needs calibrations and comparison with the standard calibrated heart beat monitors.

V. LIMITATIONS AND CONCLUSIONS

This paper presents the design and implementation procedure for a cost-efficient and low power consumption remote heart rate monitor. This device could help to improve and revolutionise healthcare delivery in developing countries and help in realization of green virtual clinic implementation proposed in [30-33]. The device is capable of monitoring HR of patients with various disease conditions which could help in detecting heart problems. Its operates smoothly and the design is quite efficient as it successfully connects the pulse sensor remotely to the front-end application. It also relays the BPM value to the terminal device in real time. However, the device is yet to be calibrated. Also, it was observed that some random high BPM pulse values were displayed when the pulse sensor is idle and gets stabilized when the sensor is in contact with the patient thumb. These limitations will be examined as part of future work.

REFERENCES

- [1] GBD 2013 Mortality and Causes of Death, Collaborators (17 December 2014). "Global, regional, and national age-sex specific all-cause and cause-specific mortality for 240 causes of death, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013". *Lancet*. 385 (9963): 117–71. doi:10.1016/S0140-6736(14)61682-2. PMC 4340604 Freely accessible. PMID 25530442.
- [2] Lawrence J. Laslett, Peter Alagona Jr, Bernard A. Clark III, Joseph P. Drozda Jr, Frances Saldivar, Sean R. Wilson, Chris Poe and Menolly Hart (2012). The Worldwide Environment of Cardiovascular Disease: Prevalence, Diagnosis, Therapy, and Policy Issues. *Journal of the American College of Cardiology*, Volume 60, Issue 25 Supplement, December 2012 DOI: 10.1016/j.jacc.2012.11.002
- [3] I. Harary, and B. Farley, "In vitro studies of single isolated beating heart cells," *Science*, vol. 131, no. 3414, pp. 1674-1675, 1960.
- [4] A. E. Aubert, B. Seps, and F. Beckers, "Heart rate variability in athletes," *Sports medicine*, vol. 33, no. 12, pp. 889-919, 2003.
- [5] G. E. Billman, "Heart rate variability—a historical perspective," *Frontiers in physiology*, vol. 2, pp. 86, 2011.
- [6] B. M. Dugan, and V. G. Dugan, "Systems and methods for heart rate monitoring, data transmission, and use," Google Patents, 2014.
- [7] B. Mallick, and A. K. Patro, "Heart rate monitoring system using finger tip through arduino and processing software," *International Journal of Science, Engineering and Technology Research (IJSETR)*, vol. 5, no. 1, pp. 84-89, 2016.
- [8] N. Daimiwal, M. Sundhararajan, and R. Shriram, "Comparative analysis of LDR and OPT 101 detectors in reflectance type PPG sensor." pp. 1078-1081.
- [9] http://www.who.int/gho/health_workforce/physicians_density/en/ visited 13/10/2018
- [10] T. F. Robinson, S. M. Factor, and E. H. Sonnenblick, "The heart as a suction pump," *Scientific American*, vol. 254, no. 6, pp. 84-91, 1986.
- [11] M. Hashem, R. Shams, M. A. Kader, and M. A. Sayed, "Design and development of a heart rate measuring device using fingertip." pp. 1-5.
- [12] S. F. Babiker, L. E. Abdel-Khair, and S. M. Elbasheer, "Microcontroller based heart rate monitor using fingertip sensors," *University of Khartoum Engineering Journal*, vol. 1, no. 2, 2011.
- [13] K. Y. Sham, and P. L.-K. Wong, "Fitness monitoring device having an electronic pedometer and a wireless heart rate monitor," Google Patents, 1999.
- [14] A. Bhat, S. Dhoble, and K. Rewatkar, "Microcontroller Based Heart Rate Monitor using Fingertip Sensors"
- [15] D. Knox, and L. Mischke, "Implementing a congestive heart failure disease management program to decrease length of stay and cost," *Journal of Cardiovascular Nursing*, vol. 14, no. 1, pp. 55-74, 1999.
- [16] S. Scalvini, E. Zanelli, M. Volterrani, G. Martinelli, D. Baratti, O. Buscaya, P. Baiardi, F. Glisenti, and A. Giordano, "A pilot study of nurse-led, home-based telecardiology for patients with chronic heart failure," *Journal of Telemedicine and Telecare*, vol. 10, no. 2, pp. 113-117, 2004.
- [17] M. Bondmass, N. Bolger, G. Castro, and B. Avitall, "The effect of physiologic home monitoring and telemanagement on chronic heart failure outcomes," *Internet Journal of Advanced Nursing Practice*, vol. 3, no. 2, 2000.
- [18] P. Szakacs-Simon, S. Moraru, and L. Pemiú, "Android application developed to extend health monitoring device range and real-time patient tracking." pp. 171-175.
- [19] M. V. Ramesh, S. Anand, and P. Rekha, "A mobile software for health professionals to monitor remote patients." pp. 1-4.
- [20] E. M. Nidhi Mutha, Ruchira Rokade, Ganesh Deshmukh, "Patient Health Monitoring Using Android Application," *International Journal of Innovative Research in Computer and Communication Engineering*, vol. 4, no. 3, pp. 13, 2016.
- [21] F. O. Turjo, M. A. Islam, S. U. Bhuiyan, T. Islam, and B. B. Pathik, "Design, simulation and implementation of a novel online patients' health checking method for physicians." pp. 1-5.
- [22] Y. A. Badamasi, "The working principle of an Arduino." pp. 1-4.
- [23] H. P. da Silva, C. Carreiras, A. Lourenço, A. Fred, R. C. das Neves, and R. Ferreira, "Off-the-person electrocardiography: performance assessment and clinical correlation," *Health and Technology*, vol. 4, no. 4, pp. 309-318, 2015.
- [24] Y. Jawahar, "Design of an Infrared based Blood Oxygen Saturation and Heart Rate Monitoring Device," McMaster University Hamilton, Ontario, Canada., Canada, 2009.
- [25] E. Jovanov, A. Milenkovic, C. Otto, and P. C. De Groen, "A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation," *Journal of NeuroEngineering and rehabilitation*, vol. 2, no. 1, pp. 6, 2005.
- [26] R. Faludi, *Building wireless sensor networks: with ZigBee, XBee, arduino, and processing:* " O'Reilly Media, Inc.", 2010.
- [27] R. Shams, A. Sayed, M.M.A. Hashem and A. Kaber, "Use of fingertip in the design and development of a device that measures the heart rate", ICCCE 2010, Kuala Lumpur, Malaysia, May 11 – 12, 2010.
- [28] H.P da Silva et al, "Clinical correlation and activity assessment of off-the-person electrocardiography", Health technology version 4, 2015, page 309 – 318.
- [29] E. Jovanov et al, "Wireless Body Area Network of intelligent motion sensors for computer assisted physical Rehabilitation", J. Neuroengineering Rehabilitation, vol. 2, 2005.
- [30] N. Faruk, N.T Surajudeen-Bakinde, A. A Oloyede, O. O Bello, S.I Popoola, A Abdulkarim, Lukman A Olawoyin, "On green virtual clinics: A framework for extending health care services to rural communities in Sub-Saharan Africa", in proc.. International Rural and Elderly Health Informatics Conference (IREHI), 2017 , pp 1-7.
- [31] N. Faruk, A. A. Oloyode, O. W. Bello, S. I. Popoola, L.A. Olawoyin, "Framework for Universal Telecommunication Access: Prospects for mHealth in Developing Economies", IEEE Conference on ICT for Communicable diseases, ISBN: 978-1-5090-6223-2, pp 46-51, 2016.
- [32] Bello, O.W., Opadiji, J. F. Faruk, N. & Adediran, Y.A. (2016). Opportunities for Universal Telecommunication Access in Rural Communities: A Case Study of 15 Rural Villages in Nigeria's Kwara State. The African Journal of Information and Communication (AJIC), (Issue 17); pp 1-26. Thematic Issue: Economic Regulation, Regulatory Performance and Universal Access in the Electronic Communications Sector. Published by University of the Witwatersrand, Johannesburg, South Africa. Available online <https://www.wits.ac.za/linkcentre/ajic/>
- [33] Faruk, N., Bello, O. W. Opadiji, J. F. & Adediran, Y. A. (2017). Socio-economic Challenges of Rural Telecommunication Access Schemes in Nigeria. International Journal of Information and Communication Technology (ICT), 14 (1); pp 194-217. Published by the Department of Library and Information Technology Federal University of Technology Minna Nigeria. Available online <https://www.ajol.info/index.php/ict/index>