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Design and Implementation of Portable Low-Cost Heart Rate Monitoring ECG System

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ABSTRACT Electrocardiogram is an important health parameter in the diagnosis of cardiovascular diseases, which are among the leading cause of death in the world including Nigeria. This research work "portable low-cost heart rate monitoring ECG system" is designed to assist patient with cardiovascular diseases to monitor their heart condition. It will also assist the medical personnel during the diagnosis of cardiovascular issues. We have used bottom-top software development approach to design an easy to use ECG system by interfacing AD8232 ECG sensor module with Arduino Nano as microcontroller to measure the electrical activity of the heart otherwise known as 'electrocardiogram' in BPM (Beat Per Minute) and display the digital reading on a 1602 LCD screen. The coding was done in Arduino IDE using C++ programming language. The system will eliminate the rigorous routine of medical trip and will go a long way to save life as most of the sickness has their root traced to the electrical impulses of the heart.

KEYWORD: ECG Sensor, Arduino Nano Microcontroller, Electrocardiogram (ECG), Patients Monitoring System, cardiovascular diseases, Portable Medical Devices

1. INTRODUCTION

Innovation of dedicated biomedical system for monitoring patient's health status will remain and always be the best option to reduce and manage hospital's service cost. Recording physical quantities of patients is also very important for health providers especially in emergencies. Therefore there is need for stand-alone system which the patient can use to regularly monitor his health status without the assistance of medical personnel. Thus, instead of frequenting the hospital and exerting more pressure on the few medical facilities, the patient will be at home and examine his health status entirely on his own. It was upon these benefits that we have proposed this project "Portable Low-Cost heart rate monitoring ECG Machine". This system can be used to monitor the heart's electrical activities also called electrocardiogram and display the digital readings on a 1602 LCD screen when the probe is accurately positioned on the body. The whole system is powered by 5V rechargeable DC source. Here, we achieved this by interfacing AD8232 ECG Sensor Module with Arduino Nano Development Board as a Microcontroller**.** In this project, our primary concern is to monitor the heart rate in beat per minute which is the most important health parameters in electrocardiography. This system can monitor the heart rate (ECG) when the probe is accurately positioned on the body. The system is non-invasive and cost-effective in diagnosis of arrhythmias. In most cases, medical experts find it difficult to interpret the paper chart-based ECG which result in misinterpretation especially the trainees (Salerno et al, 2003). It is likely that our device which gives digital reading will reduce this misinterpretation.

No doubt, the size of the medical facilities and medical personnel are far smaller, or even negligible when compared to the number of patients it handles and the continuous

increase in the number of health issues and diseases worldwide. Most times, the doctors get frustrated by the large number of patients they see every day. The patients on their own side are made to waste large proportion of their time queuing for medical attention, especially in the developing countries like Nigeria. Sometimes, these patients have to travel long distance for medical checkup, even for minor issues. Even normal routine medical visit is not spared in this situation as patients waste their valuable time and resources travelling most times to meet their doctors. It was as a result of these challenges that we have proposed this project "Portable Low-Cost ECG Machine". The proposed system is aimed at providing the patient the opportunity of monitoring his heart status entirely on his own, without the assistance of medical personnel using this "smart device". In addition to other medical equipment in the ambulances, this system will be a very handy tool for medical

industries as it will go a long way to save life, especially in the case of emergency.

Moreover, for patients on regular routine visit, they will no longer have to waste their time and resources to travel to see their doctors as they can examine their health status using this system, as most of the sickness has their root traced to heart's electrical impulses also called ECG. For many years, people are dying due to problems that are associated with heart issues. Thus, heart issues should not be treated lightly. This disease can be managed by monitoring and analyzing the Heart rate or ECG as early as possible.

2.0. CONCEPTUAL FRAMEWORK/REVIEW

The design and implementation of a portable low-cost heart rate monitoring ECG system is grounded in the integration of biomedical engineering principles, signal processing techniques, and affordable hardware components. This conceptual framework outlines the components, processes, and interactions that enable the effective monitoring of heart rate using electrocardiogram (ECG) signals in a portable, cost-effective manner.

At the core of the system is the ECG signal acquisition process, which involves detecting the electrical activity of the heart through surface electrodes. The captured ECG signals are then processed, analyzed, and displayed in real-time to provide valuable insights into the heart's rhythm and rate. The system is designed to be portable, affordable, and easy to use, allowing for continuous heart rate monitoring outside of clinical settings.

2.1. Overview of relevant technology

Previously conducted researches on health monitoring system have shown several variations over the decades, a few of which are reviewed here. One of the already existing systems uses an ARM7 processor module for the emergency transportation of the patient data. They enable monitoring of the ambulance using Google maps. They have also incorporated wireless technology like GPS and GSM modems to provide medical care as soon as possible. It also includes pulse sensor and temperature sensor, and the information is sent in the form of SMS. There is also a proposed mobile health monitoring system for the elderly, which deals with smart phones and wireless body sensors, and monitors the health of the elderly. In the case of emergency, the smart phone with the elderly person will give an alert to the people who are pre-assigned so that they can arrange for an ambulance. This system creates a platform for communication between the elderly person's health condition and their family members irrespective of the distance (Senthil et al, 2019).

Micro Electro Mechanical Systems (MEMs) and Microcontrollers have grown more inexpensive, smaller, and power-efficient, thanks to advancements in the integrated circuit industry. As a result, more embedded technologies are being developed and adopted by healthcare professionals. Smartphone technology has also incorporated these integrated systems. With rising internet penetration through mobile phones in most emerging nations, the Internet of Things (IoTs) will be embraced at a quicker rate. The Remote Health Care system incorporates these ideas to create a system that improves people's quality of life (Grefenstette and Schultz, 2017).

In 2005, Dr. Greg Clinton of University of California developed an IoT Based Remote Patient Health Monitoring System, and the conclusion is that the developed system modules can be refined and manufactured as a single circuit. The fact that all of the circuit components utilized in the remote health detection system are readily available was also discovered during project design (Marija Seder, 2019).

In 2008, An American Medical Practitioner, William Gold developed a "Healthcare Monitoring System with capability to detect ECG, blood pressure and temperature. It was reported that the average accuracy for each sensor in measuring the health parameter is 99.21% for temperature measurement, 99.26% for pulse rate measurement, 99.17% for Systolic pressure and 98.72% for diastolic pressure. The measured data are transmitted to the IBM Bluemix Cloud platform with 1.53 milliseconds per sample of data. The DE1-SoC platform uses the onboard RJ45 port to connect to the Internet. A local web page was developed to allow the user to view the results from the measurement and finally perform the disease prediction. The IoT function of the proposed system can function once it is connected to Ethernet with an Internet connection. The IoT framework on the Internet is developed using the IBM Bluemix Cloud platform with API and Cloud supported by IBM. The results are stored in cloud storage according to the type of health parameter. These previous parameters will remain inside the cloud and as a reference for doctors and users to know the current health trend. The stored health parameters are available to doctors and users through the web page developed on IBM Bluemix.

The comment feature from the doctor were successfully stored in the cloud and displayed on the web page once a patient choose to view it (Ram B., 2018).

In 2012, an English Health Engineer developed a Patient Health Monitoring System. It was reported that the reading of the patient's different essential indicators, followed by an evaluation at cloud, and then a warning to the doctor or concerned persons about the patient's health status are done within some seconds. It keeps track of vital indicators and detects any irregularities. These irregularities inform the medical personnel automatically, reducing the need for manual monitoring. The data is sent to the cloud platform using the MQTT connection. This communication protocol sends the readings of crucial patients' vital senses to a web interface, which then visually displays the data (Lam M., 2019).

In 2017, Japanese Scientist, Beny Kia developed a Smart Healthcare Monitoring that uses IoT. The system exhibited a prototype for an autonomous system that enables continuous monitoring of multiple health indicators as well as the prediction of any disease or issue, sparing the patient the agony of repeated hospital visits. The system might be utilized in

hospitals to collect and store massive volumes of data in an online database. An application can also be used to get the findings from a mobile device. The technology might be enhanced further by including artificial intelligence components to assist clinicians and patients. Data mining may be used to seek regular patterns and systematic relationships in disease, including the medical history of many patients' parameters and their associated outcomes. For example, if a patient's health parameters change in the same way as those of a previous patient in the database, the consequences might be predicted. If similar patterns are detected again, it will be simpler for doctors and medical researchers to devise a remedy (Ram B., 2018).

Dr. Clover Smith of US Health Ministry developed an IoT Based Health Monitoring System and Challenges in 2018. The importance and advantages of incorporating IoT into remote health monitoring systems was practically proven by this system (Grefenstette and Schultz, 2017).

Sham et al, (2021) reviewed paper on Design & Development of Electrocardiogram machine.

Their device is designed to record single channel of full-spectrum ECG. It stores this enormous amount of information in the memory for further correspondence. Wireless technique is used to remove burden of holter monitor. It can monitor ECG of a patient, who is far apart. The device will analyze ECG for real time and will display On Android Based Mobile.

In 2012, Al-Ghatrif M. and Joseph L. carried out a research on a brief review of history to understand fundamentals of electrocardiography**.** They found that, the last decade of the 19th century witnessed the rise of a new era in which physicians used technology along with classical history taking and physical examination for the diagnosis of heart disease.

Jaehyo et al, (2021) developed a wearable wireless electrocardiogram detection system using Bluetooth low energy**.** They developed a wearable ECG monitoring module that can be worn on each wrist and communicate wirelessly. In this work, The MCU (CY8C4247LQI-BL493, Cypress, USA) including an analog-to-digital converter (ADC), an operational amplifier (op-amp), and BLE, were used. During the measurement of an ECG signal, the system is configured as a wrist-type system and aims to minimize the discomfort experienced by the user owing to restricted movements. The Left Arm (LA) and Right Arm (RA) electrodes were placed on the left and right forearms, respectively. The potential difference was measured through a wireless node on each wrist. A 3.7 V, 120 mAh lithium polymer battery was used to perform operations for 290 min, including data processing and BLE. The developed device in this study is predicted to significantly improve the wearability and usability of health tracking systems that can be applied in clinical, sports, and military fields.

3.0. METHODOLOGY

The design and implementation **of a** portable low-cost heart rate monitoring ECG system involves a step-by-step process of hardware selection, system design, and signal acquisition, signal processing, and testing to ensure that the final product is both effective and reliable. This methodology outlines the approach for building and implementing the system, emphasizing simplicity, affordability, and portability.

3.1. System Design and Component Selection

The system was designed with the aim of achieving accurate heart rate monitoring in a compact, low-cost form. The primary components selected include:

- **Electrodes**: Three electrodes were used to capture the ECG signal. These include one for the positive lead, one for the negative lead, and a ground electrode. Disposable electrodes were selected to ensure hygiene and usability.
- **Amplifier Circuit**: An operational amplifier (Op-Amp) based circuit was used to amplify the ECG signal, as the raw ECG signal has very low amplitude and needs to be strengthened for processing.
- **Microcontroller**: A low-power microcontroller was chosen for processing the amplified ECG signal. The microcontroller was also responsible for controlling other components of the system such as display, communication, and power management.
- **Display**: A small, low-power LCD **or** OLED display was used to show the heart rate and, optionally, the raw ECG waveform.
- **Power Supply**: A **rechargeable** lithium-ion battery was selected to power the system, ensuring portability. A **DC-DC converter** was used for voltage regulation to ensure stable operation of the components.
- **Wireless Communication Module**: For remote monitoring, a Bluetooth **or** Wi-Fi module was integrated, allowing data to be transmitted to mobile devices or cloud platforms.

3.2. Design Consideration

Here, we have used bottom-top software development approach, which is, designing each module individually and then carry out unit testing, before finally integrating them as a whole.

In this work, "Portable Low-Cost heart rate monitoring ECG Machine", we have used AD8232 ECG Sensor Module interfaced with an Arduino Nano as a Microcontroller to monitor the electrical signal of the heart, otherwise known as ECG and display it on a 1602 LCD screen. Our ultimate aim is to provide a smart device that can assist the patient in monitoring his ECG status entirely on his own, without the assistance from the medical personnel. However, it is possible to monitor other health parameters like atrial fibrillation, Blood Oxygen, Body Temperature, Saline Level, etcetera, if the system is modified.

The whole system was contained inside a Perspex container to protect it from moisture and dust and it is powered by a 5 V rechargeable DC source. An analog switch was used to ON and OFF the system to save the battery life. The entire system was

simulated using both Proteus and Multisim simulation software.

The coding was done in Arduino IDE (Integrated Development Environment) using C++ Programming Language, after which it was tested, debugged, and then uploaded into the Arduino Nano Development Board.

3.3. Design Architecture of the system

In this work, "Portable Low-Cost heart rate monitoring ECG Machine" we used AD8232 ECG Sensor Module interfaced with Arduino Nano to monitor the ECG status of an individual and displays it on a 1602 LCD screen. The Arduino Nano serves as a Microcontroller that control and coordinates the activities of all the components used in this system (http://www.alldatasheet.com).

The whole system was contained inside a Perspex container to protect it from moisture and dust. An analog switch was used to ON and OFF the system to save the battery life. The system is powered by a 5 V rechargeable DC source.

The simulation was done in both Proteus and MultiSim simulation software.

3.4. Block Diagram of the System

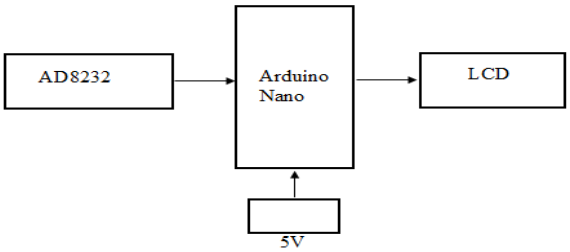

Figure1: Block Diagram of the System

From the block diagram shown in figure 3.1 above, the Arduino Nano serves as the Microcontroller, which control and coordinates the activities of the AD8232 ECG Sensor Module and the 1602 LCD screen connected to it. We have powered this Arduino Nano from an external 5V DC source through its Vin pin.

3.5. Circuit Diagram of the System

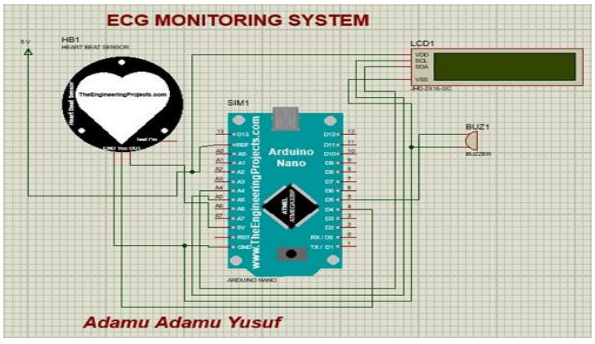

Figure 2: Circuit Diagram of the System

From the circuit diagram shown in figure 3.2 above, the Arduino Nano serves as the Microcontroller, which control and coordinates the activities of the AD8232 ECG Sensor Module and the LCD screen connected to it. We have powered this Arduino Nano from an external 5V DC source through its Vin pin. The AD8232 ECG Sensor Module has its OUT and VCC pins connected to pin D4 and 5V pin of the Arduino Nano respectively, as the sensor is 3.3V enabled.

We have connected an I2C (Inter-Integrated Circuit) Module to the 1602 LCD screen as this will reduce the number of connections from 12 to 4, although increase the cost of the project. The 1602 LCD has its SDA (Serial Data) and SCL (Serial Clock) connected to pins A4 and A5 of the Arduino Nano respectively, while its VCC pin is connected to the external 5V DC source. As an improvement, we have connected an active Buzzer to pin D5 of the Arduino Nano. This Buzzer will beep with the rhythm of the heart rate.

The GND of AD8232 ECG Sensor Module, the GND of the Buzzer and the GND of the 1602 LCD screen are tied together and connected to the GND pin of the Arduino Nano. The purpose of this common GND (Ground) connection is to provide a common reference Ground voltage. Without this common reference Ground, the system will never work properly.

4. RESULTS

Figure 3: Portable Low-Cost ECG Machine

4.1. Result Evaluation and Discussion

While testing the device, the person was asked to remove his upper clothing and shave his chest hairs so that the electrode can be attached to the skin properly. When the analog switch is turn ON, it takes about 2 seconds to power. After these 2 seconds, it asks the user to place the probe correctly. Then the user places the probes by unmasking the pad of electrode with yellow head and places it on the skin of left arm or left chest. Then he unmasks the pad of electrode with red head and places it on the skin of right arm or right chest. The third pad is place on the skin of right leg or in between the yellow and red probes to complete the circle. The system then read the ECG in BPM (Beat per Minute) of the user, and displays it on the 1602 LCD screen.

Figure 4: Placement of probe and testing of the system

The project, "Portable Low-Cost heart rate monitoring ECG Machine" works very well. The testing results shows that the system can effectively read the ECG (heart rate) in BPM (Beat Per Minute) of the user once he places the probes in the right positions of his body and displays it on a 1602 LCD screen.

5. CONCLUSION

Today, we are in the world of automation. Knowingly or unknowingly, we have been using different types of sensing and automating instruments in our daily life.

The project "Portable Low-Cost heart rate monitoring ECG Machine" is practically proved by using an AD8232 ECG Sensor Module interfaced to an Arduino Nano Microcontroller to monitor and read the ECG in BPM (Beat Per Minute) of the user and display it on a 1602 LCD screen. Thus, eliminates the rigorous routing of medical trip. This system will go a long way to save life as most of the sickness has their root traced to the electrical impulse of the heart, otherwise known as electrocardiogram or ECG. Moreover, for patients on regular routine visit, they will no longer have to waste their time and resources to travel to see their doctors as they can examine their health status using this system, and without the assistance from the medical personnel.

The Arduino Nano controls and regulates the activities of the AD8232 ECG Sensor Module and the 1602 LCD screen interfaced to it. The testing results shows that once the system is powered, it takes about 2 seconds to on. After this, the patient has to places the probes on his body. The system will automatically read his ECG in BPM (Beat Per Minute), and subsequently displays it on a 1602 LCD screen.

A lot of factors determined the accuracy of this system. These factors are the environmental phenomenon in which the system was tested as well as the quality of the sensor used. These factors majorly affected the Microcontroller. The accuracy of the system is dependent on the sensor used. Thus, the nature of the sensor and its accuracy defined the accuracy of this system.

5.2. Recommendation for Future Studies

The most effective method to increase the accuracy of this system is the inclusion of better ECG Sensor Module, and the use of more powerful Microcontroller like the ESP32 with higher processing speed. Although the project cost might increase, but the accuracy will definitely increase as well as the problem space where the system can be used. The system can also be equipped with more sensors so that it can be able to measure more health parameters like body temperature, salinity level, etc.

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