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A Wearable Device-Based IoT for ECG and Heart Rate Measurements

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ABSTRACT

A wearable electrocardiogram monitoring system is necessary for aged care patients. The proposed wearable device enables monitoring of electrocardiogram (ECG), Heart Rate Variability (HRV), and other vital signals with contemporary wearable-linked devices facilitating such monitoring. This work explains the communication between the patient and the doctor through the Internet of Things (IoT), utilizing the Arduino IoT Cloud platform, which provides all the necessary data for diagnosing heart diseases. ECG and heart rate data are collected using a wearable monitoring node and transmitted directly to the IoT cloud via Wi-Fi. It introduces an inventive IoT-based health monitoring system that utilizes the ESP32 Wi-Fi module for communication with the internet and incorporates diverse sensors to measure critical health parameters, including ECG and heart rate sensors. In general, the wearable device is considered inexpensive, low-energy-consuming, and very beneficial for heart patients. Experimental results of this system offered robust and efficient performance for health monitoring. It can be relied upon to monitor the patient and evaluate the health condition remotely.

1. INTRODUCTION

Biomedical engineering plays a very important role in controlling and measuring biosignal processing in the human body. The human body provides biosignals, which conceal mysteries, enabling researchers, healthcare professionals, and developers to uncover them for clinical decision-making or to create experiments used in other applications [1].

The electrocardiogram (ECG) signal is regarded to give important information about cardiac diseases. Therefore, a precise description of the ECG signal properties will help detect abnormalities within the signal and enhance predictions. The ECG signal records the electrical pulses of the heart, including the direction and magnitude of the signal. Electrical flow is produced by the depolarization and repolarization of the atria and ventricles. A standard ECG signal cycle consists of three waves, the P wave, the QRS wave, and the T wave, as shown in Figure 1. Furthermore, the ECG signal includes many intervals: QRS is the electrical activation of the heart's main pumping chambers; RR is the time between successive QRS complexes; and QT interval focuses on the timing and duration of cardiac electrical activity. The amplitude and shape of the waves and the interval duration affect the signal characteristics and whether or not it is normal [2]. Due to the distinction of heart-related disease diagnosis, ECG monitoring has been commonly employed in medical research and hospitals. Traditionally, the ECG signal is detected through stationary and large apparatuses in professional medical institutions. This type of apparatus cannot be wearable or portable. Moreover, patients must frequently visit the hospital, which will imminently increase the difficulty on hospitals. Therefore, a low-cost wearable system for ECG signal detection is highly desired. Wearable ECG monitoring systems have appeared, which can detect ECG signals using a sensor and transmit the signal to the smartphone through wireless transmission techniques, such as Zigbee and Bluetooth [3].

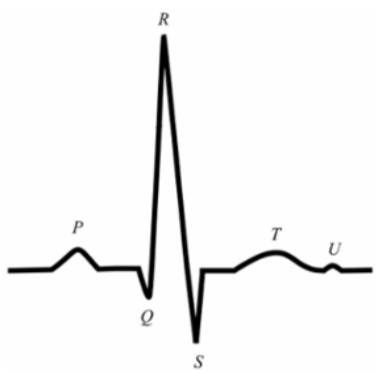


Figure 1. ECG signal

Due to the tremendous development in wireless communication systems and personal computers in the last two decades, they have been used in clinical information systems. The Internet of Things systems play an important role in our time, as it is the developed stage of the Internet. In medical uses, it has provided a technological solution for patients and doctors by providing medical supplies for personal use and controlled by doctors and hospitals, such as stethoscopes, blood pressure measuring devices, heart ECG, sugar tests, etc. [4]. The Internet of Things has enabled increased connectivity to the outside world and expanded human freedom through protocols and algorithms that facilitate global communications [5]. It is a simplified device used to record the electrical activity of the heart. It may contribute to the diagnosis of some diseases that may affect the heart, such as irregular heartbeats, angina pectoris, and heart attacks. Moreover, the heart rate monitoring system is developed using IoT technology to detect the heartbeat of the patient to monitor the risk of heart attack, and also for regular checkups [6].

A variety of scientific works are described for designing ECG devices to monitor and measure heart rate. In 2018, a central system was designed that uses ZigBee for wireless transmission and derives its energy from the patient's energy. This system is used to monitor and analyze patient data continuously [5].

Wai et al. [4] proposed a device that provides advice to the patient at all times, in addition to measuring their vital signs. Communication is achieved between the device and the doctor's computer through the Ubidots application in the Internet of Things, which allows the doctor to continuously examine the patient at any time and place. In 2020, the researchers proposed a real-time continuous ECG signal that was transferred between the transmitter and receiver utilizing RF wireless modules and Arduino boards [7].

While Bushnag [2] proposed a portable ECG monitoring system that collects two types of input data: benchmark data from the ECG-ID database and real-time data that are collected by an ECG device.

In 2023, researchers utilized microcontroller boards of various types in designing an electrocardiogram receiving circuit. Microcontroller circuits offer low-cost and lightweight devices, providing the user with great ease of use [8].

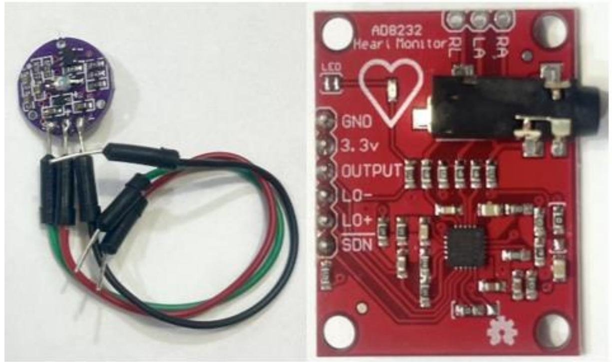
In addition to the above works, in 2024, a comparison between two types of heart rate sensors was achieved that used the Java language to collect data from the database in real-time [9]. Additionally, Zang et al. [10] designed and developed a cost-effective, non-invasive, user-friendly device and wearable that combines phonocardiogram (PCG) and ECG detection capabilities.

In this work, patients' vital indicators, ECG, and pulse rate are monitored by the specialist doctor using various sensors connected with a microcontroller embedded with Wi-Fi to allow the system to connect to the internet. An IoT Arduino cloud is used as a free platform, and it is considered the recognizable adjective of the proposed work, and can be connected to a mobile application to remotely monitor patients.

2. CONSTRUCTION OF A PATIENT MONITORING SYSTEM

The proposed construction of the patient monitoring system consists of three stages:

Stage 1. Sensor units, which include (ECG and heart rate sensors). ECG sensor Ad8232 to read heart data from the human chest. AD8232 is an integrated signal conditioner component block that monitors heart activity by conditioning electrical impulses generated by the heart [11, 12]. Ad8232 sensor operates at a low supply voltage (2.0V to 3.5V, typically 3.3V) and consumes low power (170µA typical). The Heart Beat Sensor is a biomedical sensor used to detect the pulse rate of a person by measuring changes in blood volume through optical methods. It consists of an LED and a phototransistor, which detect changes in blood volume under the skin to measure pulse rate, and to measure heart rate in beats per minute (BPM) or display an analogue signal representing the pulse. It is a key component in health monitoring systems and is widely used in fitness trackers, smart watches, and medical devices [13]. Figure 2 represents the ECG and heart rate sensor.



(a) AD8232sensor (b) Heart rate sensor

Figure 2. The used sensors

Stage 2. Microcontroller (Arduino Uno ESP. 32 Wi-Fi) and Cloud platform (IoT). The ESP32 is a Microcontroller that uses a dual-core Ten silica LX6 microprocessor, 520 KB of SRAM, and 448 KB of ROM. Boasts robust Wi-Fi capabilities, supporting the 802.11 b/g/n standard and operating in the 2.4 GHz band, and has digital I/O Pins. ESP32, a widely used microcontroller board, has gained popularity for developing heart rate sensors due to its cost-effectiveness, versatility, and ease of implementation. Moreover, ESP32's capability for wireless communication allows heart rate data to be transmitted to external devices, such as smartphones or computers [14-17].

Fog computing is a model in which specific capabilities, such as computation, storage, and network services, are distributed between edge devices and traditional centralized cloud computing, providing a suitable solution for latency-sensitive IoT applications. Although Cisco coined the term, many researchers and organizations have provided definitions from different perspectives. For example, reference [7] provides the following general definition: “Fog computing is a geographically distributed computing architecture with resources consisting of heterogeneous devices (including edge devices) interconnected at the edge of a cloud-connected network in various ways that cooperate to provide flexible computing, storage, and connectivity (and other tasks and services) in an isolated environment to a wide range of customers [3, 18]. The Open Fog Consortium also provides the following definition: “Fog computing is a horizontal system architecture with tiers of distributed resources that provide computing, storage, and control services via the network anywhere along the continuum from things to the cloud.” Fog computing is essentially an extension of the cloud, but closer to the things that run on the Internet of Things.

As Figure 3 shows, fog computing acts as an intermediary between the cloud and edge devices, called fog nodes, which can be deployed anywhere connected to the network. Any device capable of computing, storing, and networking can be a fog node, such as industrial controllers, switches, routers, and embedded servers [18]. The IoT cloud provides a convenient and fast way to store large amounts of patient-specific ECG data obtained from the monitoring node [19]. There are many remote applications used in phones, and Arduino is used in the Internet of Things, such as Arduino IoT Cloud. This application communicates with all the sensors in our phones, such as global positioning systems data, ECG, temperature, pressure, and light sensors, etc. It is stored in the cloud variables automatically [20]. The Arduino IoT Cloud provides data exchange between multiple devices and is monitored from anywhere and at any time [18, 21].

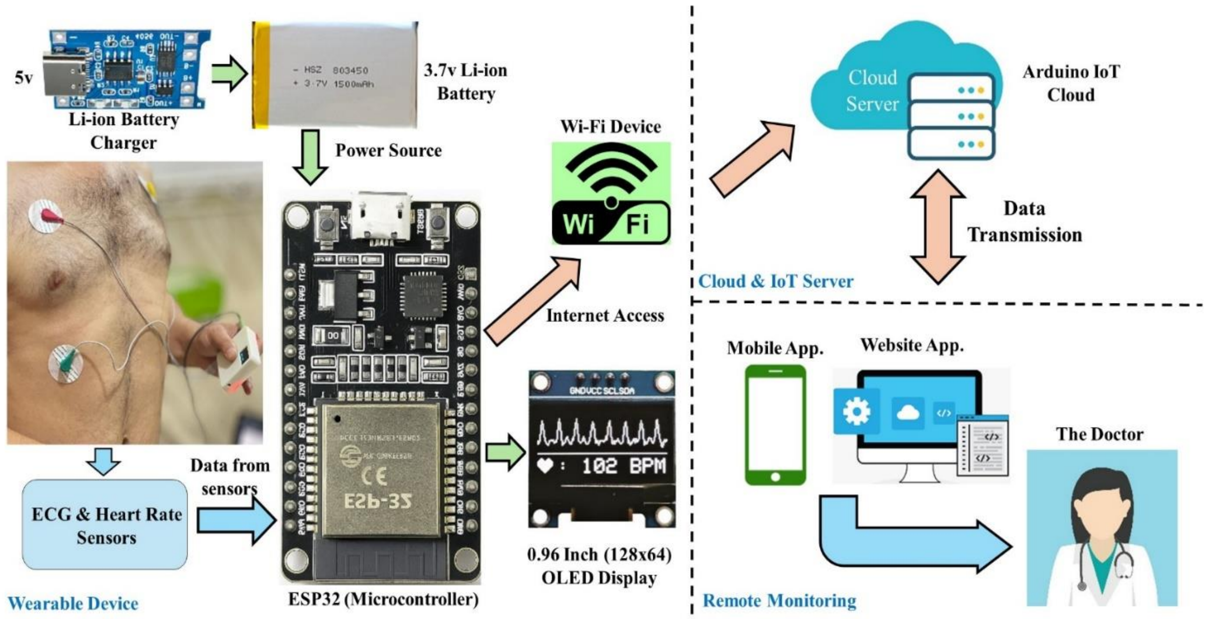


Figure 3. Proposed construction of a patient monitoring system

Graphical User Interface (GUI) is a graphical interface on an IoT device through which the user can give commands and control the device. GUI is usually used as a smartphone application or website. The authorized person can access the system and view the results through one of the interfaces used. The smartphone interface provides faster access to data, while the website interface provides a better way to store and update data [11]. In this work, an Arduino IoT Cloud remote application in mobile is used with ESP32, as shown in Figure 4.

Figure 4. IoT cloud remote application

3. THE PROPOSED WEARABLE DEVICE

The 3-lead ECG is an essential device in medical specialities and the diagnosis of heart patients. It can display the heart basics, such as ECG Waveform and real-time heart rate, all in one small device. Heart rate signals are collected from one of the patient's fingers using the heart pulse rate sensor, which works on the principle of infrared rays IR (IR Transmitter-Receiver Pair). An amplifier is used to amplify the signal and make it readable. However, the advancement of medical devices necessitates the use of small pocket devices to enable the patient to carry them easily with the same efficiency. A designated system with three electrodes placed on the patient's chest in a triangular shape around the heart. Figure 5 shows the wearable device, which is a small device that can be worn by the patient, as its weight does not exceed 50 g, equipped with a rechargeable Li-ion battery that lasts for more than 24 hours with contours operating and is also equipped with an Organic Light Emitting Diodes (OLED) screen to display the device data (internet connection status, charging level, and heart rate). In addition to the device being portable, the patient does not have to visit the health center or hospital. The patient’s data is taken continuously and in real time, and be patient's vital indicators are monitored remotely.

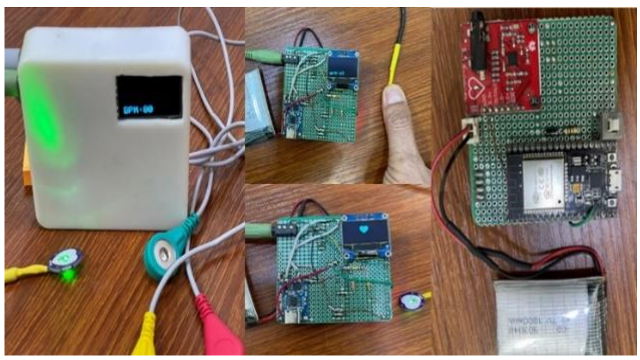


Figure 5. Outer, inner, front and back sides of the proposed device configuration

The proposed wearable device can be divided into two parts:

3.1 The proposed electronic board

The primary component of the ECG device is the ESP32, and sensor boards for pulse rate, heart monitor recording, and AD8232 make up the electrical board. The AD8232 ECG is the primary component of an electronic board and is crucial for high-gain and high-resolution electrical signal detection and measurement of the heart [13]. Tables 1 and 2 show the functions and specifications of the components used in the device.

The heart's electrical impulses are measured, amplified, and recorded during an ECG. This recording, often referred to as an electrocardiogram (ECG), gives details about the heart's pacemaker, also known as the sinoatrial or sinus node, which initiates each pulse, as well as the heart's speed, rhythm, and nerve conduction routes. An ECG may occasionally indicate that the heart is enlarged (maybe as a result of excessive blood pressure, for instance) or that the heart is not receiving enough oxygen due to a blockage in the coronary arteries, which are blood vessels that feed the heart with blood [18-23].

Table 1. The main functions of all system components

No.	Components	Functions
1	TP4056	A linear, charger for lithium-ion battery[a].
2	Li-ion Batt.	Provides a DC voltage of 3.7V[b].
3	ESP32WiFi	Processing data, connecting to Wi-Fi[c].
4	AD8232	Extracts, amplifies, and filters small biopotential signals, even in noisy environments[d].
5	Heart pulse rate sensor	Measures the frequency of the heartbeat by detecting blood volume changes under the skin[e].
6	0.96-inch OLED	Displaying text, graphics, and basic animations[f].

Table 2. Specifications for all sensor systems

No.	Components	Specifications
1	TP4056	Input voltage: 4.5V ~ 5.5V. A full charge voltage: 4.2V. Power: 4.2 W. Charging accuracy: 1.5%.
2	Li-ion Batt.	A nominal voltage of 3.7V, a charging cut-off voltage of 4.2V.
3	ESP32WiFi	The ESP32 is a Microcontroller that uses a dual-core Ten silica. Boasts robust Wi-Fi capabilities.
4	AD8232	Integrated signal conditioning block intended for ECG and other biopotential measurement applications.
5	Heart pulse rate sensor	Consists of an LED and a phototransistor, which detect changes in blood volume under the skin to measure pulse rate, and to measure heart rate in BPM.
6	0.96-Inch OLED display	Typically features a resolution of 128×64 pixels and uses the SSD1306 driver IC. They commonly interface via I2C (also known as IIC).

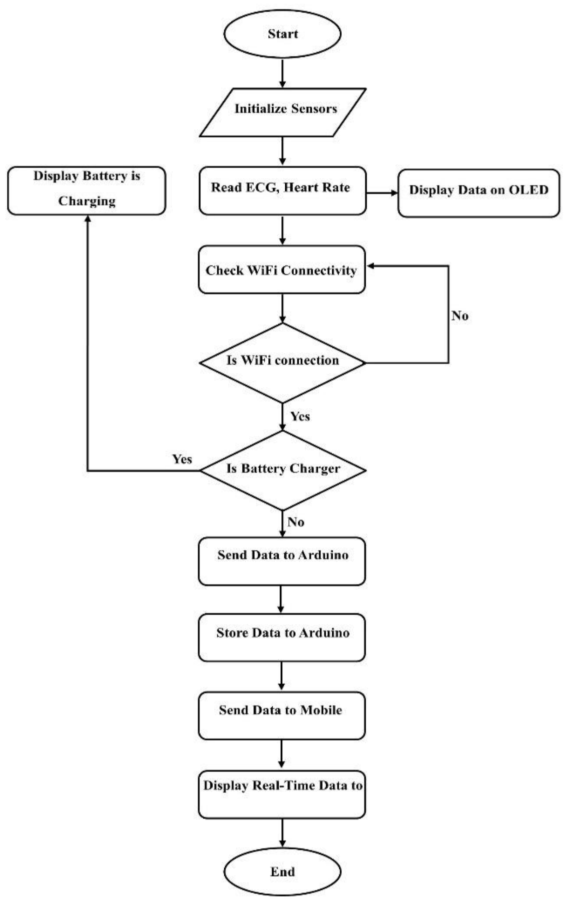


Figure 6. Manuscript methodology flowchart

An examiner applies small, spherical sensors that adhere to the skin to the subject's arms, legs, and chest to obtain an ECG. Twelve leads are used in a typical ECG, sometimes known as a twelve-lead ECG. These electrodes are painless and needle-free. The direction of the electrical currents in the heart during each beating is measured by these electrodes. Wires link the electrodes to a machine, which creates a trace, or record, for every electrode. The electrical activity of the heart is displayed from several perspectives in each tracing. The tracings form an electrocardiogram. An electrocardiogram takes about 3 minutes and has no risks [11, 24].

To achieve these readings, a pulse sensor is used for measuring heart rate [16]. ESP32 is used to achieve communication and transfer of information between the sensor unit and the Internet of Things [19-27]. Figure 5 represents the inner electronics contents of the proposed work.

3.2 The software of the proposed device

The software consists of two parts. It depends on the type of components and the programming method used. The first part is the open-source Microcontroller (ESP32 wifi), which is connected to the sensors used; each sensor needs a library to read the measured data from the patient. Libraries are loaded into the programming code used. The Integrated Development Environment (IDE) is used to write the software for the ESP32. Through the code that was written, all the sensors and connected pins were defined. Worth noting, the IDE is a single application that handles all the essential steps of programming a microcontroller board. This includes:

Code editing: A text editor within the IDE allows you to write code (written in the C language or what is called Arduino C).

Compilation: The IDE converts your human-readable code into machine code that the Arduino board can understand.

Uploading: It then sends the compiled code to the Arduino board via a USB connection.

Figure 6 illustrates a flowchart of a wearable device-based IoT system for patients with cardiac issues. Comprising sensor modules, an IoT platform, and a mobile application. The sensor module comprises ECG and heart rate sensors, both of which are connected to a microcontroller. The IoT platform acts as a gateway, collecting sensor data from the controller, compiling it into IoT cloud packets, and then sending it to the mobile application.

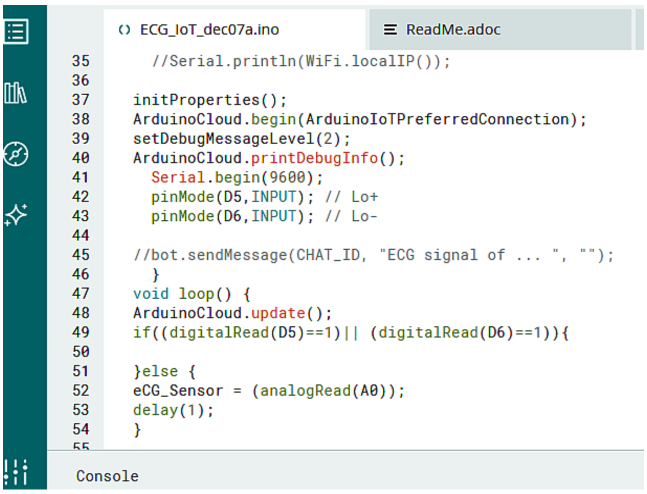


Figure 7. Proposed software of the work

The IDE simplifies the process of programming Arduino or other boards, making it accessible to beginners and experienced users alike. It provides a user-friendly interface for all the necessary steps involved in creating and deploying code. The second part is the cloud and IoT server programming. The Wi-Fi and Internet Protocol (IP) settings are configured to connect to the Internet using an embedded ESP32 protocol. The free Arduino Cloud IoT platform allows data monitoring via a mobile application or the website available on the platform. Through the cloud IoT platform, the things used in the proposed system were identified, and the data processing to be displayed on the mobile application screen or through website monitoring has been secured. Figure 7 represents the software implementation of the proposed work.

4. RESULTS

A wearable device-based IoT for ECG and heart rate measurements has been successfully implemented and simulated, as shown in Figure 5. IoT capabilities are integrated into the device components, enabling patients to access their data (ECG and heart rate), monitoring via mobile devices or computers using the Arduino IoT Cloud platform, as shown in Figure 8 and Figure 9. On the other hand, the OLED screen is integrated into the device, which provides a visual display for the patient, enabling him to see his heart rate. These features provide ease of use of the wearable device, facilitate the process of reading data by the patient, and also enable the device to be easily charged with energy. During the testing, the wearable device showed reliable heart rate readings and an ECG. Overall, the features of the Internet of Things have achieved their goals and provided easy-to-use and practical solutions for monitoring patients with heart muscle problems.

In addition to the above results, the comparison between Jumper JPD-500E Digital Fingertip Spo2 for heart rate monitor, which is considered one of the most accurate devices in the medical field, was used to compare the proposed system's obtained results. Several males and females of different ages had their heart rates read in three statuses (relaxing, walking, running), in both methods. First, using the Jumper device and second, using the proposed system, as seen in Table 3, the results of the proposed system demonstrated acceptable accuracy and a low error rate, especially in the low-rate heart rate.

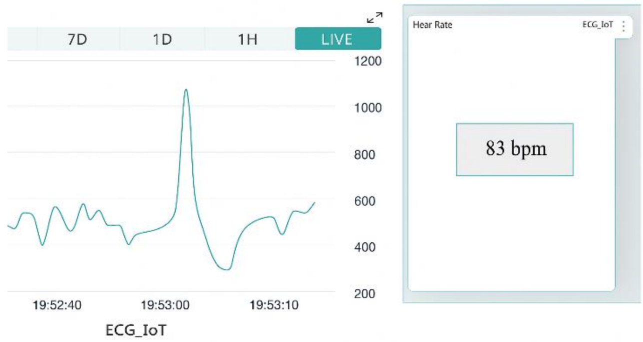


Figure 8. Real-time data on mobile

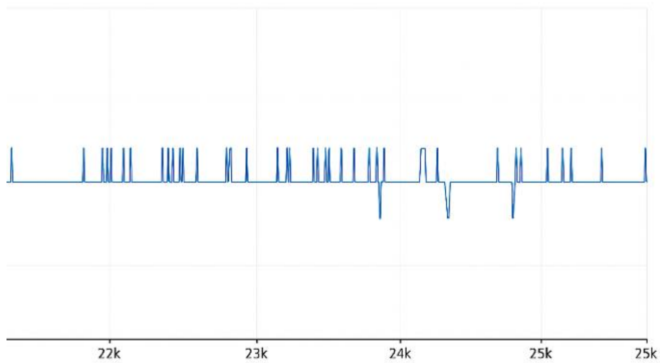


Figure 9. Result of ECG on PC

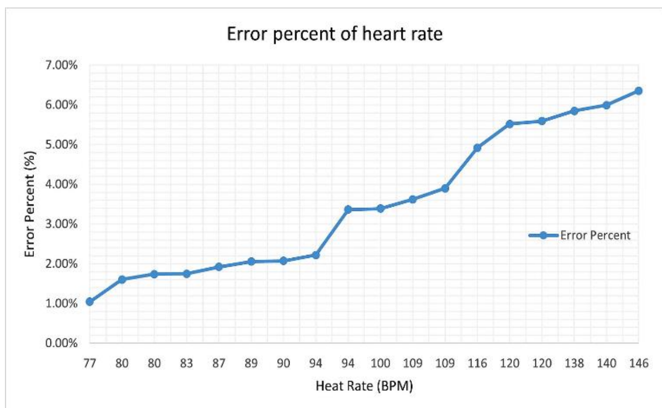


Figure 10. Error percentage of heart rate

Table 3. Comparison of the obtained results for some different specific statuses in the two methods

Gender	Age (Year)	Statuses	Heart Rate (BPM)		Error Rate (%)
			Jumper	Proposed	
Male	18	Relaxation	79	80.4	1.74
Male	18	Walk	92	93.8	1.92
Male	18	Run	118	120.1	1.75
Male	30	Relaxation	81	82.7	2.06
Male	30	Walk	98	99.6	1.61
Male	30	Run	133	138.4	3.90
Male	41	Relaxation	89	94.2	5.52
Male	41	Walk	112	115.9	3.36
Male	41	Run	141	146.3	3.62
Female	16	Relaxation	76	76.8	1.04
Female	16	Walk	88	90	2.22
Female	16	Run	102	108.5	5.99
Female	22	Relaxation	77	79.7	3.39
Female	22	Walk	85	89.4	4.92
Female	22	Run	112	119.6	6.35
Female	40	Relaxation	85	86.8	2.07
Female	40	Walk	103	109.1	5.59
Female	40	Run	132	140.2	5.85

Figure 10 shows the error rate of the heart pulse read by both methods. There is a slight increase in the error rate with the higher heart rate for both genders. Taking into account the different ages of the volunteers and they then performed some exercise for five minutes, and their heartbeat rate was subsequently measured. Thus, the proposed low-power and low-cost system showed acceptable results and small error rates.

5. CONCLUSIONS

In this paper, a wearable device for patients with heart problems was designed, using an ECG sensor and a heart rate sensor built on the Internet of Things using the free Arduino IoT Cloud platform. The device allows monitoring of patients by IoT Remote Application or using the platform's website. Tests were performed on several males and females of different ages, and results were taken in different statuses (Relaxation, Walk, and Run). The results were compared with the results of a well-known device in health centers, and had very low error rates. Furthermore, ECGs were performed on several patients of different ages, and their data were analyzed and sent via the Arduino IoT Cloud platform, displaying on the IoT Remote Application or the Arduino IoT Cloud website. It would also be interesting to implement some algorithms for real-time QRS complex analysis, allowing for preliminary analysis of ECG signals using waveforms or artificial neural networks. It is also possible to add space to an SD card, where the data is stored as local storage, eliminating the need to send it to a platform, meaning that data analysis can be performed offline. As a low-power wearable device powered by a rechargeable battery, it can harvest energy from bodily sources by harvesting the electrical potential of the human body.

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