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ORIGINAL STUDY

An IoT-based Smart Wearable E-health Monitoring System for Patients with Heart Diseases☆

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Abstract

Smart and affordable healthcare has gained favor due to the world's growing population and increasing medical costs. It is essential to develop an effective e-health monitoring system that can identify abnormalities in real-time and support professionals in making diagnoses based on the data acquired. Recent advancements in mobile and cloud computing have led to the development of numerous cloud-based healthcare services and products. In this paper, an IoT-based wearable e-health monitoring system is presented. It continually monitors the patient's vital signs, including body temperature, heart rate, blood oxygen saturation, and an electrocardiogram (ECG). Using an IoT platform, we designed and implemented an E-Health monitoring system for heart disease monitoring using the remote Blynk and mobile applications. Healthcare professionals can economically monitor patients' health at any time from any location using a compact and easily transported distant monitoring system. Heart diseases that can be detected from the implemented system are arrhythmias, coronary heart disease, heart attacks, and cardiomyopathy. To test the system performance, we compared the system findings with that measured by Japan Fukuda ECG Machine Cardisuny C110 Digital Single Channel, Apple, and Samsung smartwatches. These systems can detect only the existence of Beats Per Minute (BPM) problems but can not transmit and diagnose them. However, the proposed system measures the vital signal parameters including the ECG signals. Is beneficial for detecting heart diseases and doctors can diagnose patients remotely. The obtained findings for Atrial Fibrillation individuals show that the accuracy of the proposed system readings for ambient temperature, object temperature, heart rate, and Saturation of Peripheral Oxygen (SpO_2) is 98.5%, 97.3%, 96.7%, and 98.3% respectively relative to Apple smartwatch readings and 97.2%, 95.3%, 96.1%, and 97.5%, respectively relative to Samsung-galaxy smartwatch readings. In addition, discussions with cardiologists and their responses to the survey about the features of the proposed suggested system reveal that it can detect heart attacks.

Keywords: Apple, Cloud-based healthcare services, ECG, E-health monitoring, Internet of things, Samsung smartwatches, Smart wearable devices and vital signs

1. Introduction

Numerous industries have benefited greatly from wireless technology due to rapid technical improvement in recent years. The Internet of Things (IoT) has been successfully applied in most of the industrial sectors, particularly automation and control, as well as the fields of health and biomedical. IoT technology is used in hospitals and private healthcare facilities. Doctors play an essential role in health check-ups in traditional systems. This procedure necessitates a significant amount of time for check-in, an appointment, and registration. Afterwards, reports are also released. Due to the

☆ This paper is written and contributed by a single author Dr. Mohammed M Abo-Zahhad. The author conceived of the presented idea to develop a wearable effective e-health monitoring system that can identify abnormalities in real-time and support professionals in making diagnoses. This is done based on the data acquired, depending on the patient's vital signs, including body temperature, heart rate, blood oxygen saturation, and an electrocardiogram (ECG). Using an IoT platform, we managed to design and implement the system for heart disease monitoring using the remote Blynk and mobile applications. The author selected the NodeMCU ESP32, the adopted sensors due to their relatively high accuracy, low cost, and small size when compared to other modules. The author used four software packages for the fabrication and implementation of the proposed system. Namely, Arduino IDE, Eagle Autodesk, SolidWorks, and Blynk Platform. The author measured and analyzed the acquired ECG signal and tested the system performance, compared the system findings with that measured by Japan Fukuda ECG Machine Cardizem C110 Digital Single Channel, Apple, and Samsung smartwatches.

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time-consuming nature of check-ups, those who are working tend to avoid or delay them. Medical staff can follow up with patients remotely using several technological tools with the help of distant monitoring as a solution. These services can deliver similar health outcomes as in-person medical meetings, provide greater patient satisfaction, and be cost-effective. The smartwatch unit collects vital signs readings using sensors, and the data collected is either sent in response to service requests or if any abnormality appeared through analyzing the collected data (Albahri et al., 2018; Alenoghena et al., 2023; Abo-Zahhad et al., 2014).

Owing to the growing use of mobile internet and Wireless Sensor Networks (WSNs), wearable/portable health monitoring devices that can monitor and record long-term health statistics without the need to frequently visit hospitals or healthcare facilities are now feasible. The two key drivers of this technology are cloud-based analytics and IoT-based data collection. In this paper, real-time health monitoring via IoT was created and developed. This simplifies the process of diagnosing and treating people with cardiac problems. The MLX90614, MAX30102, and ECG AD8232 are non-intrusive sensors that are used to record patient health information such as body temperature, heart rate, blood oxygen saturation, and heart ECG signals. The collected data is sent to the IoT cloud, where it may be viewed. This is done through a web-based server or any Internet Operating System (IOS) or Android application. Thus, doctors can use the cloud platform to diagnose patients in distant areas. Patients and their families can also use this cloud service to receive regular updates and view medical records. These records can be continuously evaluated remotely by a doctor or archived and retrieved later for examination. As a result, patients will be able to manage their busy daily schedule with their responsibility to take care of their health. The system's price, mobility, and ease of use contribute to its benefits as being particularly user-friendly for the public and the elderly. Additionally, there are no complex electronics.

The following is an outline of the research's significant contributions.

(1) The development of a new medical system involves utilizing Internet of Things (IoT) technology to remotely track and examine real-time health data of patients. The system focuses on detecting or diagnosing heart events. This sends medical notifications to patients, relatives, carers, and medical professionals.
(2) Doctors and nurses can use a mobile app to keep track of a patient's temperature, heart rate, oxygen levels, and heart rhythm. So, they can find irregular heartbeats, coronary heart disease, heart attacks, and heart muscle problems and get notifications when vital signs go beyond a predetermined threshold.
(3) Generating live visualizations that depict the crucial statistics of patients' excellent performance to avoid hospitalizations.
(4) The developed prototype is compact and can easily be moved to different places. This system works well for monitoring healthcare and has been proven to be effective.
(5) Examining the feasibility of integrating wearables and IoT into medical systems for home environments to deliver real-time monitoring, prompt intervention, and enhanced patient care while lowering healthcare expenditures and hospital visits.
(6) To conduct a comparative study, several experiments were carried out between the system findings with that measured by Japan Fukuda ECG Machine Cardisuny C110 Digital Single Channel, Apple, and Samsung smartwatches. The results obtained indicate that the proposed system's accuracy readings for ambient temperature, object temperature, heart rate, and SpO2 are 98.5%, 97.3%, 96.7%, and 98.3%, respectively relative to readings from Apple smartwatches, and 97.2%, 95.3%, 96.1%, and 97.5%, respectively relative to readings from Samsung-galaxy smartwatches. The results reveal that the suggested system performs better than various commercial systems.

The following sections constitute the remaining part of this paper. The literature review for IoT-based smart wearable healthcare monitoring systems for heart disorders is introduced in Section II. The proposed system concepts, functions, and a brief background are presented in section III. It includes the cloud server working principle and ECG signal. A comprehensive breakdown of the proposed system's implementation is provided in Section IV. In Section V, the proposed system results as well as a comparison with the existing systems are discussed. In Section VI, the paper is concluded, and future research is highlighted.

2. Literature review

Globally, heart disease is the number one cause of mortality. Its prediction is a difficult task since it calls for both extensive experience and cutting-edge information. Recently, medical organizations have begun to use IoT technology to gather sensor data for the diagnosis and prognosis of heart conditions. Tools that track and record heart rate or pulse are referred to as heart rate monitors. These gadgets can now be small, wearable, and use a variety of accurate sensors because of modern technology. Researchers have focused a lot of their efforts on heart disease monitoring and diagnosis, but the results are not very precise. Fig. 1 illustrates one of the oldest heart-monitoring system architectures using smartphones and wearable sensors (Leijdekkers, 2007). The interface with the monitoring application was aimed at elderly patients and should be straightforward, individualized, and customized to the user's health status. This requires vocal engagement when a patient has poor vision, or vibration and flashing lights when a patient has hearing loss. The main limitations of this system are it is complex and expensive since it is based on the integration of many subsystems such as an ECG monitor, oximeter, blood pressure, Global Positioning System (GPS), smartphone, and secure data server. Recently, there are numerous applications available that use wireless sensor networks, the Internet of Things, and smartphones for heart health monitoring. A wireless system that uses microcontrollers to monitor heartbeat and temperature utilizing Zonal Intercommunication Global-standard (ZigBee) was presented in (Samie et al., 2019; Sangaiah et al., 2020). The system was created for patients who do not appear to be in a life-threatening situation but still need to be observed by a clinician or family regularly. In the event of a medical emergency, a Short Message Service (SMS) is sent to the doctor or a family. As a result, by providing early aid, we can easily save many lives.

The authors of Ref (Liu et al., 2019). enabled real-time and continuous individual ECG monitoring employing wearable and IoT technology. They create a unique wearable 12-lead ECG SmartVest device for the early diagnosis of cardiovascular illnesses that is based on the IoT. It is made up of a dry ECG electrode-based sensing layer, a Bluetooth-enabled network layer, a platform for cloud-based calculations and storage, and server and application layers for signal processing and decision-making. It gives necessary data to doctors and family members via a web interface that facilitates remote diagnosis and enables authorized individuals to keep an eye on the patient's health. However, they only addressed the issue of lightweight QRS detection for wearable ECG applications and real-time signal quality assessment. They did not investigate the capability of the system to benefit from all the collected vital signs.

The author of (Khan, 2020) proposed an IoT system to assess heart disease using a Modified Deep Convolutional Neural Network (MDCNN) more precisely. He demonstrated a prototype of a smartwatch and heart monitor that is attached to the patient and measures blood pressure and electrocardiogram (ECG) for wireless ECG signal transfer utilizing an AD8232 sensor and Raspberry Pi-based Internet of Things. However, the proposed system here is restricted to categorizing what is

Fig. 1. Heart-monitoring system architecture (Leijdekkers, 2007).

received sensor data as normal and abnormal. So, its usage for practical situations is thus dubious (Gjoreski et al., 2020). describes a technique for detecting chronic heart failure (CHF) based on cardiac sounds. The approach combines traditional machine learning (ML) and comprehensive deep learning (DL). The DL trains from a spectro-temporal representation of the signal, while the traditional ML learns from expert characteristics. This method's essential shortcoming is that it is not real-time. It has been assessed using recordings from 947 individuals from six datasets that are available to the public plus one CHF dataset that was gathered specifically for this study. The authors of (Gjoreski et al., 2020) present encouraging findings for the detection of various CHF phases as well as for the separation of recordings between healthy persons and patients.

The transition of healthcare from in-person consultation to telemedicine is made possible by the development of IoT technology. The authors of (Islam et al., 2020) presented a smart healthcare system in an IoT environment that can continuously track patients' vital signs and the state of their bedrooms. To collect data from the patient's environment to the hospital environment, they deployed sensors. The developed scheme's error percentage falls within a predetermined range (5%) for each example. Medical staff receives information about the patient's condition via a gateway so they may assess and evaluate the patient's current state. Although the newly implemented smart healthcare system monitors patients' vital signs, it is bulky and no reported cases have been provided to support its use in actual practice.

The authors of (Elhoseny et al., 2018) investigated the growing demand for big data research, particularly for applications involving health care. In a big data environment like Industry 4.0 applications, the adoption of cloud computing and the IoT paradigm in the healthcare industry may present medical IT with several alternatives. The resources needed to manage such data in a cloud-IoT setting are still a significant obstacle. To effectively manage a large amount of data in integrated industry 4.0, which requires processing and analyzing big data coming from various sources such as sensor data, without human intervention (Elhoseny et al., 2018), proposed a new model to optimize virtual machine selection (VM) in cloud-IoT health services applications.

Recently, a method for detecting arrhythmia in IoT applications automatically utilizing CNN and long-short-term memory (ConvLSTM) technology was developed by Hammad et al. (2022) The suggested models, which address difficulties like overfitting and working with multiple leads of ECG signals, transform the input ECG signals into 2D images and then classify the data using the information included in the images. The authors assessed several publicly available datasets, including MITBIH, PhysioNet 2016, and PhysioNet 2018. On these datasets, overall accuracies of 0.97, 0.98, 0.94, and 0.91 were obtained, respectively. In (Nancy et al., 2022) bidirectional long-short-term memory (Bi-LSTM) was used to track and forecast the risk of developing a cardiac disease. Outstanding outcomes from the system included an accuracy of 0.98, precision of 0.989, sensitivity of 0.988, specificity of 0.988, and F-measure of 0.9886, which exceeded expectations.

More recently (Islam et al., 2023), proposed an IoT-based system using the AD8232 ECG sensor module for gathering ECG signal data, the MAX30100 for measuring blood oxygen level and heart rate, and the MLX90614 non-contact infrared sensor for determining the body temperature. A pre-trained deep-learning model based on a convolutional neural network (CNN) with an attention layer is used to categorize likely diseases using the acquired data. This server-based system sends the data to be analyzed. As a result, the tedious and error-prone process of manually extracting features is no longer necessary. In addition to CNNs, attention layers that highlight the most instructive aspects in the input data can also be used to improve deep learning algorithms, enhancing the performance of the model. The device also offers a report on the patient's oxygen level and heart rate, indicating whether they are within normal limits. If any critical irregularities are found, the system quickly connects the user to the closest physician for additional diagnostics. Combining IoT and deep learning technologies might alter the healthcare industry by enabling proactive disease prevention, remote monitoring, and early detection of medical conditions.

3. Theory and background information

3.1. Cloud server working principle

The system that has been suggested is based on the IoT concepts of collecting data and transferring it to the cloud. A Node Microcontroller Unit (NodeMCU) Espresso if Systems (ESP32) acts as the hub for all the wearable sensors that are utilized to measure the patient's body parameters. They gather the data, upload it to the cloud, and show the results on the mobile application Transmission Control Protocol/Internet Protocol (TCP/IP) communications are used to safely convey the data. The Internet of Things (IoT) is a network of physically connected objects that can be accessed. The ‘thing’ on the IoT can be a person with a monitor or a car with built-in sensors, i.e., items with an IP address that can gather and send data over a network without the need for manual intervention. Table 1 demonstrates the IoT worldwide healthcare market in USD Billion. The embedded technology in the devices allows them to interact with internal states as well as the outer environment. This has an effective impact on the decisions made. It allows devices/objects to observe, recognize, and comprehend a situation or environment without requiring human assistance. It can link devices that are part of many different systems to the internet. When objects and instruments can represent themselves digitally, they can be accessed from everywhere (Al-Sarawi et al., 2020; IoT in Healthcare Market to, 2016).

The connectivity between devices and objects makes it possible to collect more data from more locations. This increases the system's productivity while also boosting safety and IoT security. Such systems are divided into six tiers: namely, smart devices and controllers, cloud servers, connectivity and protocol communication, data storage and accumulation, data analysis, and computing, as well as user application and report generation. Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) are the three main categories of cloud computing services. There will be two types of clouds: private and public. A public cloud offers services to anyone with an internet connection. A closed network or knowledge hub that offers hosted services to a select number of users with the right access and permissions is an example of a personal cloud. Data that may be accessed from any location via web user end servers or applications are archived and uploaded employing cloud services. A collection of cloud services referred to as ‘IoT cloud’ enables the Internet of Things. Whether real-time processing and archiving of IoT data is required or not, this category comprises the underlying infrastructure. The standards and services needed for connecting, managing, and protecting a variety of IoT devices and applications are also included in the IoT cloud. Organizations employ IoT cloud services when they are available, just as they do with other types of cloud services, such as software-as-a-service, instead of constructing an information center or other on-premises infrastructure to provide those services locally.

In the proposed system, we used Blynk as the IoT platform. It was created with the goal of quickly and easily developing and implementing smart IoT devices. Blynk is a platform that allows you to operate Arduino, Raspberry Pi, and other microcontroller boards via the Internet using IOS and Android apps. It is a digital dashboard where we may drag and drop widgets to create a graphic interface for the proposed system.

To connect the microcontroller board with the Blynk Cloud and Blynk's server, Blynk supports connection methods such as Wi-Fi, Ethernet, Bluetooth, Cellular, and Serial. The components of the Blynk platform are as follows.

(1) Blynk app builder that allows the creation of applications for projects utilizing a variety of widgets. It is compatible with both Android and IOS devices.
(2) Blynk server that oversees all communications between the Blynk-enabled mobile device and the hardware. We have the option of using the Blynk Cloud or running our own Blynk server locally. Its open-source software can easily handle tens of thousands of devices and can even be run on a Raspberry Pi.
(3) Blynk libraries that allow connectivity with the server and handle all incoming and outgoing commands from the hardware and Blynk app. They are compatible with all the major hardware platforms.

When combined, the components result in an IoT application that is fully functional and can be used anywhere using a pre-configured connectivity type. Through the Blynk Cloud or Blynk server, we may control the hardware from the Blynk app on the patient's mobile device. Furthermore, it works the other way around, sending rows of processed data from the hardware to the Blynk app.

3.2. Electrocardiogram (ECG)

An ECG is a graph, typically printed on paper to make the analysis simpler. The heart muscle constricts in response to the electrical depolarization of muscle cells, unlike other muscles. It is demonstrated

Table 1. Global (worldwide) IoT in healthcare market revenue and forecasts 2015–2025.

Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Market Revenue (B$)	10.26	12.21	14.59	17.50	21.08	25.47	30.87	37.53	45.73	55.85	68.31

by the varying electrical activity of the heart muscle over time. This electrical activity is amplified and recorded for a brief amount of time before being compiled into an ECG. The sinus node, a specialized tissue area in the upper right atrium (RA), depolarizes on its own to initiate the usual cardiac cycle. A pulse of electrical depolarization can travel through the RA and into the left atrium owing to the left atrial (LA) enlargement. The atrioventricular (AV) node is the only pathway for electrical depolarization from the atria to reach the ventricles in the normal heart since the atria and ventricles are physically separated by an electrically inert fibrous ring. Before the wave of depolarization descends the interventricular septum (IVS) and enters the right ventricle (RV) and left ventricle (LV) through the His bundle and the right and left bundle branches, the AV node momentarily pauses the electrical signal. Normal conduction results in the simultaneous contraction of both ventricles, which is essential for maximizing cardiac function. After the heart has fully depolarized, the myocardium must repolarize to prepare it for the subsequent cardiac cycle's depolarization.

The term ‘surface’ ECG refers to how the ECG is measured: a set of electrodes are applied to the patient's skin. The IVS acts as a conduit for the electrical depolarization wave as it moves from the atria to the ventricles. Depolarization consequently typically happens from the superior to the inferior side of the heart. The wave of depolarization often moves to the left since the heart is positioned in the chest to the left and the left ventricle has more muscle mass than the right. The broad direction in which electrical depolarization moves across the heart is known as the electrical axis. A fundamental tenet of ECG recording is that when a wave of depolarization approaches a recording lead, it produces a positive or upward deflection. A negative or downward deflection occurs when it moves away from a recording lead. The electrical axis is typically downhill and to the left but knowing which ‘direction’ each recording lead measures the ECG, allows us to estimate it more correctly in specific cases. The electrical activity of the heart is illustrated as it varies over time, which is an important element of the ECG. In other terms, the ECG can be viewed as a graph, with the vertical axis representing electrical activity and the horizontal axis representing time as shown in Fig. 2. Standard ECG paper moves at a speed of 25 mm/s while real-time recording is being done. As a result, 1 s is represented by 25 mm along the horizontal axis on the printed ECG. On ECG paper is a grid with small and large squares printed on it. Each little square on the horizontal axis

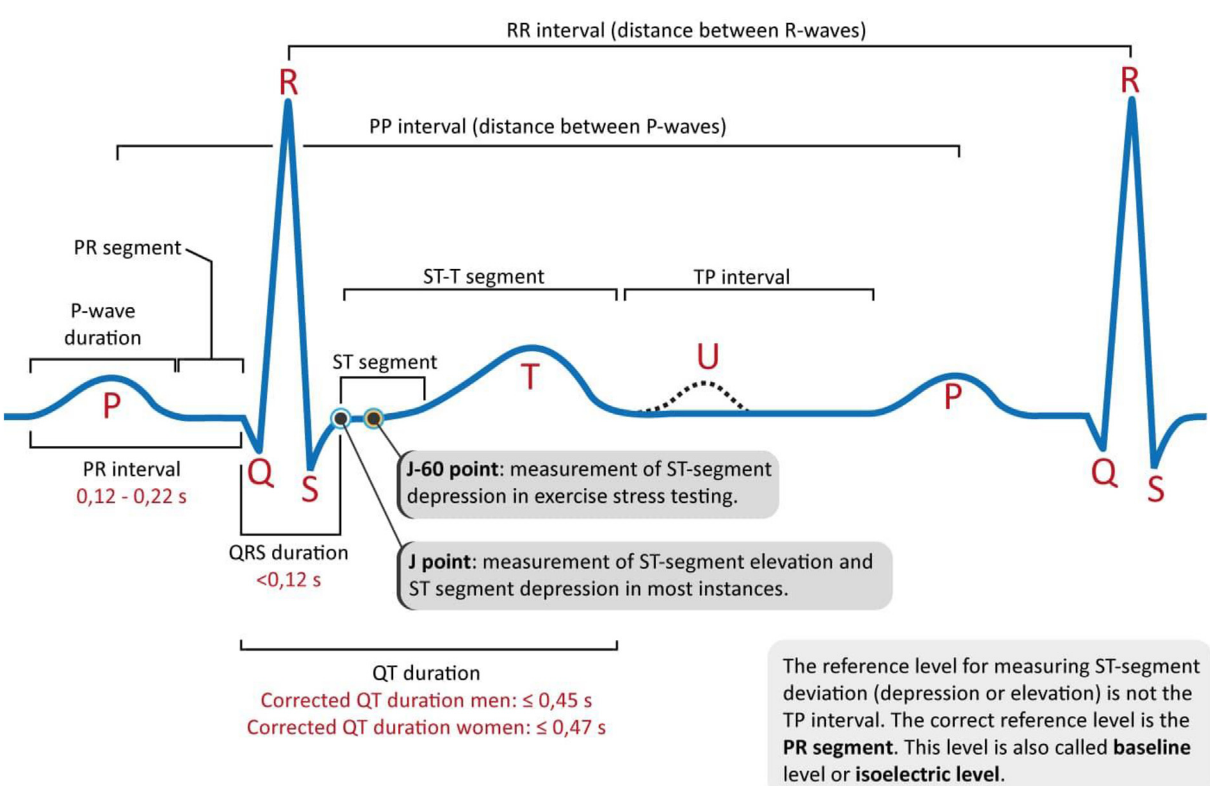


Fig. 2. The classical ECG wave with its most common waveforms, important intervals, and points of measurement (olimex.com/Products/Modules/Biofeedback/ECG-GEL-ELECTRODE, 2023).

represents 40 ms (ms), whereas each larger square contains 5 smaller squares, each of which equals 200 ms. This ECE representation allows for heart rate calculations and the detection of aberrant electrical conduction within the heart.

(1) P-waves are indicators of atrial depolarization.
(2) The time between an electrical activity happening in the atria and ventricles is measured by the PR interval.
(3) The QRS complex represents the depolarization of the ventricles.
(4) The ST segment, an isoelectric line, displays the interval between the ventricles' depolarization and repolarization.
(5) The ventricular repolarization waveform is the T-wave.
(6) The QT interval is an indicator of how long it takes the ventricles to depolarize and then repolarize.

4. The proposed system

4.1. System components

In the proposed system, the NodeMCU ESP32, temperature sensor MLX90614, heart rate, and SpO_2 sensor MAX30102 and ECG AD8232 are selected due to their relatively high accuracy, low cost, and small size when compared to other modules. Besides using some other components such as three lead electrodes, PCB, 3D printing filament, Power source, Jumpers, shunts, and SMD Toggle Switch are used. The working principle of the main sensors used is given as follows.

4.1.1. MLX90614 temperature sensor

The MLX90614 infrared sensor collects infrared radiation signals from objects and bodies and converts them into electrical signals, which are then delivered to a converter after noise amplification by an amplifier. The electrical signal is transformed into digital signals, which are then stored in internal memory before being sent to the Supply Chain Management (SCM) control system to be processed. MLX90614 infrared temperature sensor Module AD8232 uses the Serial Peripheral Interface with a microcontroller (Zhang et al., 2015).

4.1.2. Pulse oximeter MAX30102 (Debashis, 2022)

This sensor uses the I2C communication protocol, which allows the sensor's SCL and SDA pins to connect with the microcontroller. Primarily it has two modes: infrared and red LEDs. As a result, if we try to inhale oxygen, which raises the oxygenated blood in the user's body, the absorption of a stronger infrared signal than that of red lights occurs, increasing SpO_2. However, when we exhale, more blood is deoxygenated than oxygenated, which absorbs more red light while transmitting more infrared light. It serves as an interface between the two primary purposes of oxygenated and deoxygenated blood to compute heart rate in BPM in the situation of the time.

4.1.3. ECG

When the body meets the ECG sensor's electrodes, the gel in the electrodes conducts electrical signals from the skin surface. There is electrical energy that spreads throughout the body with every oxygenated and deoxygenated blood pump in and out. However, because of its incredibly low power, it is not felt. In this case, the low-power electrical signal is conducted by the conductive gel inside the electrodes. and then amplifies it to obtain the ECG's analogy values, which are then plotted on the ECG paper (Caterine et al., 1997; Samol et al., 2019; Avila, 2019).

4.2. Adopted software

The following four software packages are used for the fabrication and implementation of the proposed system.

(1) Arduino IDE: open-source Arduino Software used to program microcontroller 'ESP32' (https://support.arduino.cc/hc/en-us/articles/360019833020-Download-and-install-Arduino-IDE., 1983; Hughes, 2016).
(2) Eagle Autodesk is a scriptable application for electronic design automation that includes functionality for printed circuit board layout, schematic capture, auto-routing, and computer-aided manufacturing (https://pxhag.sunsilkscreens.com/post/eagle-cad-software/4397805, 2023; Scarpino, 2014).
(3) Dassault Systems' SolidWorks is a 3D printing-compatible computer-aided design and engineering program for solid modeling that is used to create wearable technology (Top 10 Favorite Features in, 2018).
(4) Blynk Platform allows the quick build interfaces for controlling and monitoring the hardware from IOS and Android devices (SeneviratnePradeeka, 2018).

4.3. Wearable system implementation

Two layers are used for the implementation of the proposed health-monitoring system. On the upper layer, the Max30102 and ECG AD8232 are installed, while the microcontroller NodeMCU ESP32 and the MLX90614 temperature sensor are mounted on the lower layer facing the skin to meet applicable standards. MAX30102 sensor has a top view square aperture that is suitable for the finger. The proposed system is added with jumpers and shunts in front of each sensor to make it easy for the user to switch them on and off separately. Also included is an SMD toggle switch for controlling data transmission to Blynk.

5. Results and discussion

5.1. Data collection

In the proposed system the Blynk application, as well as monitoring using the Arduino IDE program, are used for the collected sensors' readings. For the activity monitoring, we began by collecting the data of the 35 individuals (25 had heart diseases, and 10 were healthy) and comparing them to data from devices used in hospitals and commercial smartwatches. Their measured body parameters include the body and ambient temperatures, heartbeat in BPM, oxygen rate in blood, and ECG of the heart. All can be viewed distantly on the Blynk app from any location where a doctor, nurse, and/or patient exist. To make it easier for cardiologists to monitor, the patient's name and national ID are displayed as well. Fig. 3 illustrates smartwatches and Fukuda Cardisuny ECG machines used as references for comparing the proposed system's measured parameters.

Over time, a series of ECGs can be acquired to track a person who has been identified as having a cardiac issue or taking medications that may impact the heart. Heart diseases that can be detected from the implemented system are.

(1) Heart irregularities, or arrhythmias, include too slow, too fast, or irregular heartbeats.
(2) Coronary heart disease: a condition in which an accumulation of fatty substances blocks or interrupts the heart's blood flow.
(3) Heart attacks: an abrupt blockage of the blood flow to the heart.
(4) Cardiomyopathy is when the heart's walls thicken or widen.

The proposed system is tested based on the picked readings of body temperature sensors, ambient temperature sensors, oxygen level sensors, and ECG sensors collected from the 35 individuals. The effect of these readings on the heart statues can be explained as follows.

(1) Body temperature sensor reading that measures the temperature of the patient's body. When the body temperature increases, the heartbeats will be faster and the blood pumps faster, so it is necessary to evaluate.
(2) Ambient temperature sensor reading that has an impact on the energetic requirements of all patients, causing changes in oxygen consumption and heart rate. No difference in heart rate was found between males and females, but oxygen consumption was higher for females and body temperature was higher for males. An inverse, linear relationship occurred between heart rate and oxygen consumption concerning ambient temperature, causing them to increase in response to a decreasing temperature.
(3) SpO_2 sensor reading that is normally measured by a pulse oximeter that indirectly monitors the oxygen saturation of a patient's hemoglobin in a patient's arterial blood. A pulse oximeter uses a sensor and/or a probe to measure SpO_2, which

(a) Apple watch [22] (b) Samsung-galaxy-watch [29,30] (c) Fukuda Cardisuny ECG machine [31]

Fig. 3. Smartwatches and Fukuda Cardisuny ECG machine used for comparison.

represents functional oxygen saturation. Further, a decrease in oxygen saturation results in increased heart rate and pulse rate variability, and thus, there is a need to measure the oxygen level to check the status of heart diseases. If the SpO_2 reading is lower than 95%, the health care provider should be called.

(4) ECG sensors are used for assessing the rhythm and heart rate. It is often utilized in detecting abnormal heart rhythms, an enlarged heart, heart attack, and heart disease, which may lead to heart failure.

The proposed system is intended for use by a range of users, including medical professionals, heart disease patients, and caregivers. Following that, 50 participants with the characteristics shown in Table 2 were requested to use the prototype and utilize the mobile application as part of the system experiment procedures to test its design and functionality. The 50 participants are categorized into four groups consisting of 5 medical professionals, 25 patients who had heart diseases and were treated in a hospital's heart care unit, 10 healthy subjects, and 10 nurses. The table shows that the sample is relatively diverse in terms of sex, with an almost equal number of male and female participants. The age category also shows that most participants are between 20 and 70 years old, with a smaller number of participants in the older age categories. The sample size is acceptable according to the World Health Organization (WHO) and relatively diverse in terms of sex and status category, with most participants being in the younger age categories. This was intentional to ensure the reliability and consciousness of the patients, as the intended users of the system are from the early and moderate stages of the disease. Hence, the low number of older participants is attributed to the fact that they are more likely to be in the last stage of the disease. Furthermore, we found that participants' resistance to new technologies increases with age since their knowledge of technology is inversely correlated with age.

Table 2. Summary of demographic characteristics of the 50 participants.

Demographic Characteristic	Category	Count	Percentage
Sex	Male	27	54%
	Female	23	46%
Status category	Patients	25	50%
	Health persons	10	20%
	Cardiologists	5	10%
	Nurses	10	20%
Age category (years)	20–29	16	32%
	30–39	10	20%
	40–49	14	28%
	50–59	6	12%
	60–70	4	8%

5.2. Participants satisfaction

To evaluate the satisfaction of participants, they were given a survey to provide their feedback on the system. In addition, a group discussion was conducted to gather their comments and suggestions. During the group discussion, the author led the discussion and encouraged participants to share their thoughts, opinions, and experiences related to the proposed system. He used open-ended questions to encourage participants to share their ideas and opinions freely and to explore their thoughts in more depth. The survey provided an opportunity for participants to share their experiences, ideas, and concerns about the system, as well as to suggest potential improvements or new features.

The questionnaire included a mix of open-ended and closed-ended questions, and participants were asked to rate their satisfaction with the system on a Likert scale of 1–5 as 1 means very dissatisfied, 2: dissatisfied, 3: neither satisfied nor dissatisfied, 4: satisfied, and 5 means very satisfied. The questions, as shown in Table 3, were designed to assess various aspects of the system, including ease of use, the effectiveness of the system in helping users to early detect heart disease, body temperature sensor reading, ambient temperature sensor reading, SpO_2 sensor reading, and ECG traces.

As represented in Table 3, the Customer Satisfaction (CAST) calculation process is used to measure the proposed system's user satisfaction levels (Gianluigi, 2015). It is calculated by summing up all 4 and 5 responses received from the participants divided by the total number of responses (which is 50 in this case). CSAT scores between 0 and 40% indicate that most users are unsatisfied with their experience, while scores between 40% and 60% are considered decent but with room for improvement. Scores between 60% and 80% indicate that most of the users are good and above 80% indicate most of the users are highly satisfied with their experience. Overall, the group discussion, and the questionnaire are valuable tools for gathering rich qualitative data and creating new insights.

Consultation with the cardiologists through open-ended discussions suggested the following when unusual parameters are observed.

(1) An increase or reduction in P-waves can suggest an issue with potassium ion concentration in the body, which can affect neuronal function.

Table 3. Participants' satisfaction scores and responses.

Question	Number of evaluators[a]	1	2	3	4	5	CSAT%
(1) Is the body temperature reading accurate?	15	0	0	0	5	10	100
(2) Is the ambient temperature reading accurate?	15	0	0	1	6	8	93.3
(3) Is the SpO_2 sensor reading accurate?	15	1	0	1	6	7	86.6
(4) How helpful are the ECG trac in showing the important waves, periods, and critical points?	15	0	1	0	5	9	93.3
(5) Have you encountered difficulties in the early detection of heart disease?	15	0	0	1	6	8	93.3
(6) Is the mobile application easy to use?	50	1	1	1	24	23	94.0
(7) Did you find the system easy to use?	50	0	1	1	27	21	96.0
(8) Are you satisfied with the compactness and lightweight design of the system?	50	2	1	2	25	20	90.0

[a] The first 5 questions are evaluated by the cardiologists and nurses, and all questions are evaluated by the 50 participants.

(2) A cardiac arrhythmia called atrial fibrillation prevents effective ventricular diastole by causing the heart to pulse irregularly. It is indicated by A missing P wave.
(3) QRS complex abnormalities may suggest heart hypertrophy or myocardial infarction.
(4) While a raised ST segment is the most common sign of myocardial infarction, missing or down-ward-sloping ST segments can also suggest ischemia.

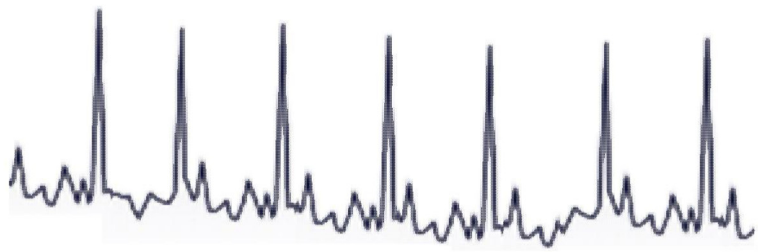
5.3. Comparison with the existing systems

In addition to the surveys with beneficials and discussions with cardiologists explained in the previous subsection, the assessment of the proposed system is carried out by acquiring the measured body parameters of healthy, and patients with heart disease volunteers. The measured parameters and the sections of the ECG plot were traced and compared to the normal ranges in terms of their suitability for quality assessment. All these measurements are examined by the 5 cardiologists. For this purpose, the data is gathered from 35 individuals; among them 10 healthy subjects and 25 of whom had heart diseases and were treated in a hospital's heart care unit. In the following, we considered examples of one person healthy, one has Atrial Fibrillation and a third one has a heart attack. The first 5 questions of the survey, given in Table 3, are evaluated by the cardiologists and nurses, and all eight questions are evaluated by the 50 participants. As explained before the last column of Table 3 includes the CSAT of each question. To display the resulting signals and parameters of some of the participants the following three cases are considered.

5.3.1. The first subject: a 35-year-old healthy male

The ECG signal of this person is gathered using the remote Blynk App. proposed system compared with that obtained by using Japan Fukuda ECG Machine Cardisuny C110 Digital Single Channel (Japan Fukuda ECG Machine Cardisuny). Fig. 4 illustrates the two ECG traces. The findings are investigated by the five cardiologists. They indicated that the ECG trace obtained from the proposed system matches that of (Japan Fukuda ECG Machine Cardisuny) for the 35-year-old healthy male. They show that person's heart is beating at 88 BPM (rate of 60−100 beats per minute). Many different heart conditions can show up on an ECG, including a fast, slow, or abnormal heart rhythm, a heart defect, coronary artery disease, heart valve disease, or an enlarged heart. Thus, the heart of this person is healthy. Fig. 5 shows the measured parameters using the UMEC 10 Patient Monitor (Mindray). A similar conclusion is noticed for the other 9 healthy persons.

For other vital signs, the data obtained via the remote Blynk mobile application of the proposed system are the ambient temperature of 25 Celsius, the body temperature of 37 Celsius, the heart rate of 88 BPM, and SpO_2 of 90%. Fig. 6 shows the measured ambient temperature and measured body parameters including the object temperature, heart rate, and SpO_2. The obtained results are compared with that obtained using Apple smartwatch readings (Avila, 2019), and with that obtained using Samsung-galaxy smartwatch readings (Main Features of Samsung Galaxy Watch, 2023; Nissen et al., 2022). Table 4 illustrates the obtained findings for this person using the three systems. It has been noticed that the accuracy relative to the Apple smartwatch is 97.5 ± 0.5% and that relative to the



(a) ECG signal of a healthy person using the proposed system.

(b) ECG signal of a healthy person using the ECG Machine Cardisuny C110 [31].

Fig. 4. Comparison between the proposed system and ECG Machine Cardisuny C110. (a) ECG signal of a healthy person using the proposed system. (b) ECG signal of a healthy person using the ECG Machine Cardisuny C110 (Japan Fukuda ECG Machine Cardisuny).

Fig. 5. Data on UMEC 10 patient monitor (Mindray).

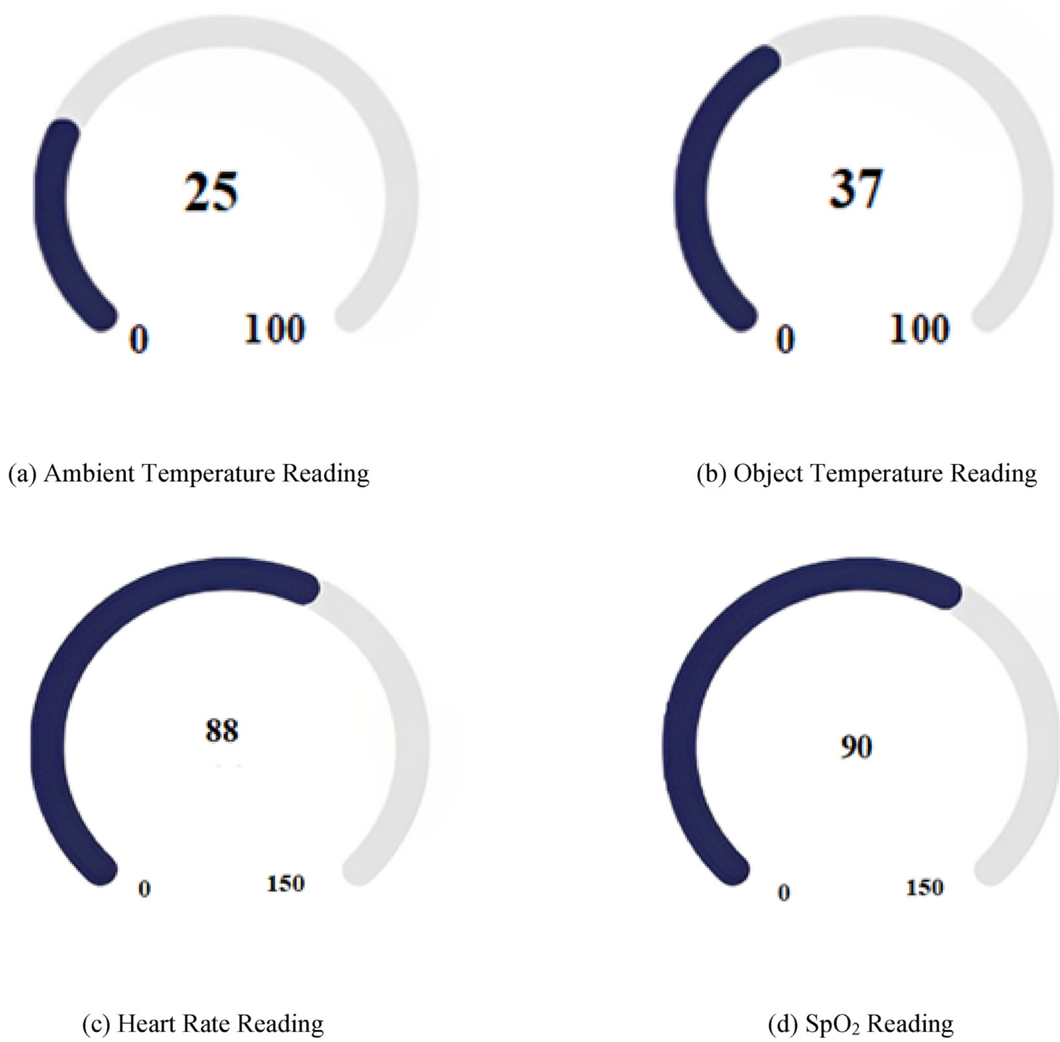


Fig. 6. Measured ambient temperature, body temperature, Hart rate, and SpO_2 readings of a healthy subject obtained via the remote Blynk mobile application of the proposed system.

Samsung-galaxy smartwatch is 95.5 ± 0.5% for all vital signals.

5.3.2. The second subject: a 50-year-old female with atrial fibrillation disease

Fig. 7 shows the measured ambient temperature, object temperature, heart rate, and SpO2 for this patient obtained via the remote Blynk mobile application of the proposed system. The obtained data are the ambient temperature of 21 Celsius, the body temperature of 36.5 Celsius, the heart rate of 135 BPM, and SpO_2 of 95%. The same subject parameters are measured by Apple and Samsung-galaxy smartwatches. The obtained findings show that the accuracy of the proposed system readings for ambient temperature, object temperature, heart rate, and SpO_2 is 98.5%, 97.3%, 96.7%, and 98.3% respectively relative to Apple smartwatch readings

Table 4. Comparison between the findings of the proposed system and SmartWatches for the first subject.

Measuring System ＼ Parameter	Ambient temperature	Object temperature	Heart rate	SpO_2
Apple smartwatch (Avila, 2019)	25.6 C°	37.8 C°	90.3 BPM	91.8%
Samsung-galaxy smartwatch (Main Features of Samsung Galaxy Watch, 2023; Nissen et al., 2022)	26.2 C°	38.5 C°	92.2 BPM	93.8%
The Proposed System	25.0 C°	370.0 C°	88.0 BPM	90%

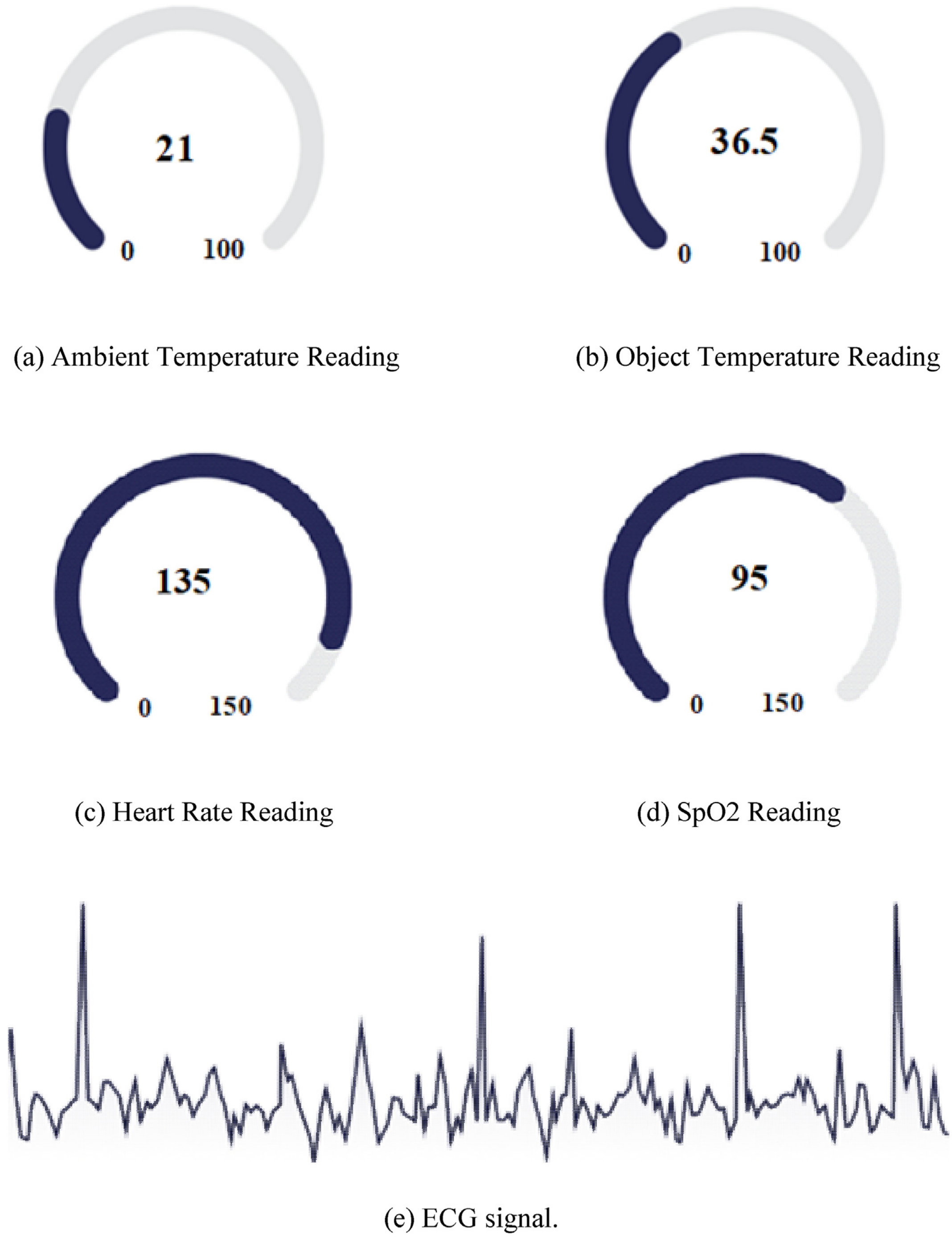


Fig. 7. Measured ambient temperature, body temperature, Hart rate, SpO_2 readings, and ECG signal of the second subject suffering from Atrial Fibrillation obtained via the remote Blynk mobile application of the proposed system.

Table 5. Comparison between the findings of the proposed system and SmartWatches for the second subject.

Measuring System ∖ Parameter	Ambient temperature	Object temperature	Heart rate	SpO_2
Apple smartwatch (Avila, 2019)	21.3 °C	37.5 °C	139.6 BPM	93.4%
Samsung-Galaxy smartwatch (Main Features of Samsung Galaxy Watch, 2023; Nissen et al., 2022)	21.6 °C	38.3 °C	140.5 BPM	92.6%
The Proposed System	21 °C	36.5 °C	135 BPM	95%

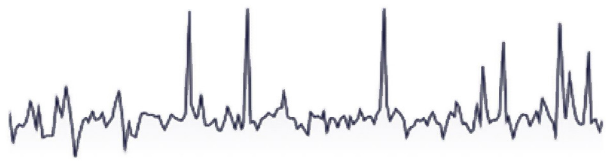


Fig. 8. ECG signal of a patient suffering from a heart attack.

(Avila, 2019) and 97.2%, 95.3%, 96.1%, and 97.5% respectively relative to Samsung-galaxy smartwatch readings (Main Features of Samsung Galaxy Watch, 2023; Nissen et al., 2022). Table 5 illustrates the obtained findings.

5.3.3. The third subject: a 32-year-old male patient with a heart attack

The ECG pattern can vary during a heart attack, which skilled medical experts can understand and use to make a diagnosis. On an ECG, a heart attack will show an elevated ST segment and a more pronounced T-wave than usual. This denotes a complete obstruction of a major artery. Here, we utilized (64-slice) multi-slice computed tomography (CT) to evaluate the viability of measuring epicardial fat volume (EFV) and identify its medical consequences. Under physiological circumstances, epicardial fat promotes and maintains the heart's ability to perform normally. Numerous clinical research has found conclusive links between elevated epicardial fat levels and coronary artery disease (CAD). All five cardiologists investigated the obtained ECG signals and indicated that it was diagnosed as a heart attack as can be noticed in Fig. 8.

6. Conclusions

An IoT-based wearable E-Health monitoring system has been developed and brought into use in this study. The system was created with the challenges that most individuals face when they have tight daily routines and frequently postpone or forget their needed health check-ups in mind. The proposed system can also help elderly persons who are going to clinics or diagnostic centers for frequent check-ups. Healthcare professionals such as doctors can monitor patients' health at any time from any location using the distant monitoring system economically supplied by the proposed system. Because this system is so compact and can easily be transported to different sites. Instead of employing huge machinery, a tiny watch like can be used to view a patient's heartbeat, body temperature, and ECG data. Doctors can remotely see data and evaluate patient health-related aspects. This is the system's main advantage, and those who live in remote places without access to doctors can profit from the equipment. Instead, the technology sends all the data and signals to a website, where distant clinicians can access the information and accurately assess a patient's heart condition. Putting in place such a system will help in the early detection of atypical cardiovascular disease conditions and the avoidance of serious consequences. Apple and Samsung watches can detect only the existence of BPM problems but can't diagnose them. However, the proposed system measures the ECG signals. So, it is beneficial for detecting heart diseases so tshat cardiologists can diagnose patients remotely.

For face-to-face consultations between medical professionals and patients, the video feature can be included. Future research might include several additional metrics that are essential in determining a patient's state, such as the degree of diabetes and respiratory monitoring. In addition, intend to start developing deep learning and machine learning models for diagnosing cardiac problems in the future (F H et al., 2022; Doolub et al., 2023; Kim et al., 2022; Tiwari et al., 2023; Chandrasekhar and Peddakrishna, 2023).

Conflicts of interest

There is no conflict of interest.

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ملخص عربي

نظام مراقبة الصحة الإلكتروني الذكي القابل للارتداء القائم على إنترنت الأشياء للمرضى الذين يعانون من أمراض القلب

اكتسبت الرعاية الصحية الذكية وذات الأسعار المعقولة شهرة بسبب النمو السكاني في العالم وزيادة التكاليف الطبية. من الضروري تطوير نظام فعال
لمراقبة الصحة الإلكترونية يمكنه تحديد حالات القلب الشاذة في الوقت الفعلي ودعم المهنيين في إجراء التشخيص بناءً على البيانات التي تم الحصول عليها.
أدت التطورات الأخيرة في الحوسبة المتنقلة والحوسبة السحابية إلى تطوير العديد من خدمات ومنتجات الرعاية الصحية القائمة على السحابة. في هذه الورقة
، يتم تقديم نظام مراقبة الصحة الإلكترونية القابل للارتداء القائم على إنترنت الأشياء. يراقب باستمرار العلامات الحيوية للمريض ، بما في ذلك درجة حرارة
. باستخدام منصة إنترنت الأشياء ، قمنا بتصميم وتنفيذ نظام مراقبة (ECG)الجسم ومعدل ضربات القلب وتشبع الدم بالأكسجين وتخطيط القلب الكهربائي
الصحة الإلكترونية لمراقبة أمراض القلب باستخدام تطبيقات الهاتف المحمول والبلينك البعيدة. يمكن لمتخصصي الرعاية الصحية مراقبة صحة المرضى
اقتصاديًا في أي وقت ومن أي مكان باستخدام نظام مراقبة بعيد مدمج وسهل النقل. أمراض القلب التي يمكن الكشف عنها من خلال النظام المطبق هي عدم
انتظام ضربات القلب وأمراض القلب التاجية والنوبات القلبية واعتلال عضلة القلب. لاختبار أداء النظام ، قمنا بمقارنة نتائج النظام بتلك التي تم قياسها
. يمكن لهذه الأنظمة أن Samsung و Apple الرقمية أحادية القناة و Fukuda ECG Machine Cardisuny C110 بواسطة الساعات الذكية اليابانية
ولكن لا يمكنها نقلها وتشخيصها. ومع ذلك ، فإن النظام المقترح يقيس معلمات الإشارة الحيوية Beats Per Minute (BPM) تكتشف فقط وجود مشكلات
بما في ذلك إشارات تخطيط القلب التي تفيد في الكشف عن أمراض القلب وتمكن الأطباء من تشخيص المرضى عن بعد. أظهرت النتائج التي تم الحصول
عليها لأفراد الرجفان الأذيني أن دقة قراءات النظام المقترحة لدرجة الحرارة المحيطة ودرجة حرارة الجسم ومعدل ضربات القلب وتشبع الأكسجين
الذكية و 97.2٪ و 95.3٪ و 96.1٪ و 97.5٪ Apple تبلغ 98.5٪ و 97.3٪ و 96.7٪ و 98.3٪ على التوالي مقارنة بقراءات ساعة (SpO2) المحيطي
الذكية. بالإضافة إلى ذلك بينت المناقشات مع أطباء القلب واستجاباتهم للمسح حول ميزات النظام Samsung-galaxy على التوالي مقارنة بقراءات ساعة
المقترح أنه يمكنه اكتشاف النوبات القلبية.