A Portable IoT-cloud ECG Monitoring System for Healthcare

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Summary
Public healthcare has recently become an issue of great importance due to the exponential growth in the human population, the increase in medical expenses, and the COVID-19 pandemic. Speed is one of the crucial factors in saving life, particularly in case of heart attack. Therefore, a healthcare device is needed to continuously monitor and follow up heart health conditions remotely without the need for the patient to attend a medical center. Therefore, this paper proposes a portable electrocardiogram (ECG) monitoring system to improve healthcare for heart attack patients in both home and ambulance settings. The proposed system receives the ECG signals of the patient and sends the ECG values to a MySQL database on the IoT-cloud via Wi-Fi. The signals are displayed as an ECG data chart on a webpage that can be accessed by the patient's doctor based on the HTTP protocol that is employed in the IoT-cloud. The proposed system detects the ECG data of the patient to calculate the total number of heartbeats, number of normal heartbeats, and the number of abnormal heartbeats, which can help the doctor to evaluate the health status of the patient and decide on a suitable medical intervention. This system therefore has the potential to save time and life, but also cost. This paper highlights the five main advantages of the proposed ECG monitoring system and makes some recommendations to develop the system further.
Keywords:
Healthcare; ECG monitoring; sensors; IoT-cloud.

1. Introduction

In light of the ongoing growth of the global population and the increasing cost of medical treatments, as well as the recent emergence of the COVID-19 pandemic that has led to lockdowns around the world, access to healthcare has become one of the most significant issues for individuals and governments alike. The pandemic has deterred many patients from going to medical centers to seek care and it has hampered the follow up and monitoring of health conditions such as those associated with the heart. Regarding the diagnosis of heart-related diseases specifically, electrocardiogram (ECG) monitoring has been widely applied for many years in both hospitals and medical research [1],[2]. However, given the current global scenario, the identification of the presence of diseases in a timely and accurate manner at low cost and without the need to attend a medical center has become a topic that is receiving more attention than ever before. Hence, the use of healthcare for patients at risk of heart attack or heart failure is attracting increasing research interest and one avenue that is being explored is the development of an ECG monitoring system that is both smart and portable.

Traditionally, an ECG is obtained by using large, stationary equipment located in a medical institution. This kind of device usually uses 12 electrodes to record ECG data due to their good performance in taking measurements over a short duration. However, this type of equipment is cumbersome and difficult to transport. This means that patients' movements and activities are severely limited during the period of data collection [3]. Moreover, as these devices are usually too expensive for home use, patients have to go to hospital frequently, which inevitably increases the burden on hospitals. Therefore, a portable system for long-term ECG signal calculation at low cost is highly desirable.

The ECG signal is one of the most important bioelectrical signals. Since its discovery in 1887, the ECG signal has been used extensively in the diagnosis of several heart disorders. The ECG signal is produced because of the contraction and expansion of the myocardium. The ECG signal consists of three major waves referred to as P, QRS complex, and T waves. The P wave represents the depolarization of the atrium, the QRS complex wave reflects ventricular depolarization, and the T wave represents the repolarization of the ventricles. A typical ECG waveform with the beat-to-beat (R-R interval) and basic waves is shown in Fig. 1 below.

Frequent or consecutive abnormal beats such as premature ventricular contraction (PVC) beats may be an indication of heart malfunction, which can cause sudden cardiac arrest (SCA) and sudden death. Sudden cardiac arrest is one of the main causes of natural death: in the USA, for example, about 325,000 adults die of SCA each year. Moreover, SCA is responsible for half of all deaths due to heart disease [1],[5]. Hence the calculation of abnormal beats is critical in clinical cardiology [2],[6]. Indeed, most cases of SCA could be avoided if early

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diagnosis were carried out based on access to timely ECG recordings. Abnormal beats can easily be recognized by eye from recorded ECG signals because they look very different from normal heartbeats. However, identifying the occurrence of abnormal beats requires the use of monitoring systems that can record many beats over a long duration.

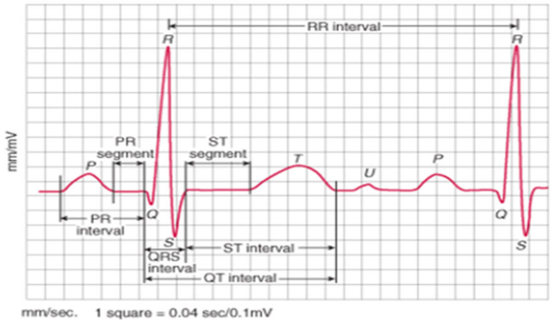

Fig. 1. ECG signal showing P, Q, R, S and T waves [4]

Therefore, in view of the ongoing existence of COVID-19 pandemic, which deters or prevents patients from going to medical centers where their health conditions can be monitored and followed up, this paper aims to propose an architecture for an ECG monitoring system based on the IoT-cloud technology. Based on the proposed architecture, a portable ECG monitoring system is designed and implemented to monitor and follow up patient health remotely, without the need for the patient to visit a medical center. Using the proposed system, the ECG data that are gathered from the human body are transmitted directly to the IoT-cloud via Wi-Fi without the need for a mobile terminal. This is because Wi-Fi can provide higher data rates and wider coverage areas. Also, to provide the user with convenient and timely access to ECG data, a storage server and HTTP web server are deployed in the IoT-cloud. The gathered data are stored in a relational database, i.e., MySQL, which can greatly improve the speed and flexibility of data storage. In addition, a web-based GUI is implemented using PHP programming language to enable doctors and patients alike to access the data services provided by the IoT-cloud easily via smart phones that run on different operating system platforms. Moreover, the proposed system calculates the total number of heartbeats, number of normal heartbeats, and number of abnormal heartbeats, the output of which can help doctors to evaluate patients' heart health and quickly decide on the most appropriate form of medical intervention. Hence the proposed system has the potential to save time, life, and cost.

The remainder of this paper is organized as follows: Section 2 presents the proposed architecture of the IoT-cloud ECG monitoring system in detail. Then, Section 3 highlights the main advantages of the proposed ECG monitoring system. Finally, Section 4 concludes the work and makes some recommendations in relation to developing the proposed system further.

2. Architecture and Implementation of IOT-Cloud ECG Monitoring System

The proposed architecture of the IoT-cloud ECG monitoring system is illustrated in Fig. 2 below. The architecture mainly consists of three components: ECG sensor boards, IoT-cloud technology, and an ECG monitoring GUI.

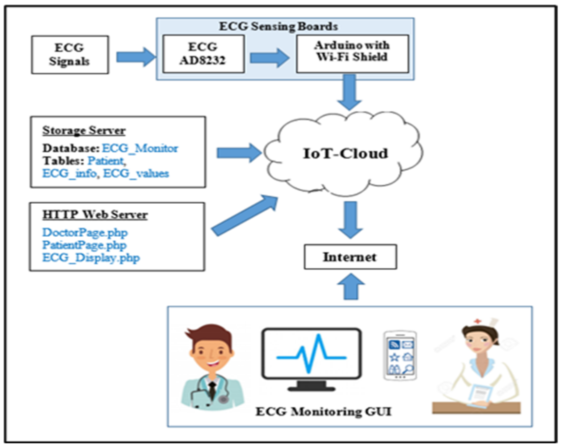

Fig. 2. Proposed architecture of IoT-cloud ECG monitoring system

A. ECG Sensor Boards

The proposed architecture of the IoT-cloud ECG monitoring system, as shown in Fig. 2 above, consists of an AD8232 ECG heart monitor sensor board and an Arduino with Wi-Fi shield board. The AD8232 ECG heart monitor sensor board is a cost-effective board that can be used to measure the electrical activity of the heart with high enough gain to get good resolution [4],[7]. This electrical activity can be charted as an ECG and output as an analog reading (ECG signal). Electrocardiography is the process of recording the electrical activity of the heart over a period of time by using electrodes placed on the body. These electrodes detect the tiny electrical changes on the skin that arise from the heart muscle's electro physiologic pattern of depolarizing and repolarizing during each heartbeat. The ECG signal can be extremely noisy, so an op amp is used in the AD8232 heart monitor sensor board to get a clear signal from the PR and QT intervals more easily. The AD8232 heart monitor sensor board has an integrated signal-conditioning block for the ECG and other bio potential measurement applications. The AD8232 heart monitor sensor board is designed to extract, amplify, and filter small bio potential signals in the presence of noisy conditions, such as those created by motion or remote electrode placement. The AD8232 heart monitor sensor board consists of nine pins. Six of these pins, i.e., GND, 3.3V, OUTPUT, LO+, LO-, and SDN, are essential for connecting and operating this board with an Arduino with Wi-Fi shield development board, as shown in Fig. 3 below. The remaining three pins for RA (Right Arm), LA (Left Arm), and RL (Right Leg) are provided on this AD8232 heart monitor sensor board through ECG electrodes are connected to, as shown in Fig. 4 below.

The Arduino with Wi-Fi shield board is an open-source microcontroller board developed by the Arduino Company. The board is equipped with sets of digital and analog I/O pins that may be interfaced to various expansion boards (shields) such as an Ethernet shield and other circuits to provide a communication facility.

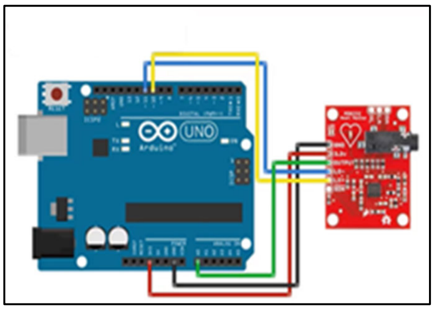

Fig. 3. Diagram of connections between AD8232 sensor board and Arduino with Wi-Fi shield board

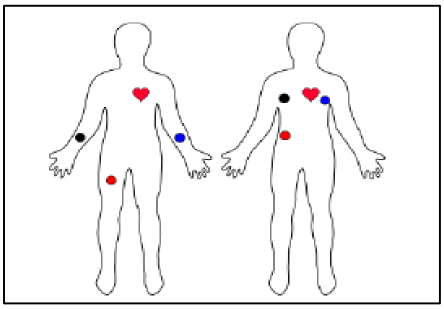

Fig. 4. AD8232 electrodes [4]

As mentioned above, this board is connected to the AD8232 heart monitor sensor board through six pins in the AD8232 (GND, 3.3V, OUTPUT, LO+, LO-, SDN). The Arduino with Wi-Fi shield gets the ECG signal data from the AD8232 heart monitor sensor board and processes it using the Arduino IDE (Integrated Development Environment) with embedded C programming on the Windows OS platform. The Arduino board has a Wi-Fi shield so it can also be used to send data to the IoT-cloud via Wi-Fi, which supports high data rates and wide coverage areas, as shown in Fig. 2 above. The Arduino with Wi-Fi shield is used in the architecture of the proposed ECG monitoring system because it not only acts as a portable computer, but also requires a DC voltage, which means that it can be used in a moving vehicle such as an ambulance.

B. IoT-Cloud Technology

The IoT is considered the next step in the evolution of the Internet because it enables common de-vices to be more intelligent and interactive [8]. The IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. An IoT ecosystem consists of web-enabled smart devices that use embedded systems, such as processors, sensors and communication hardware, to collect, send and act on data they acquire from their environments. When a device is IoT-enabled, it can share the sensor data it collects by connecting to an IoT gateway or other edge device whereby the data are either sent to the cloud to be analyzed or analyzed locally. Sometimes, these devices communicate with other related devices and act on the information they get from one another. The devices do most of the work without human intervention, although people can interact with the devices, for instance, to set them up, give them instructions or access the data. The type of connectivity, networking and communication protocols that are used with these web-enabled devices largely depends on the specific IoT applications that are deployed.

The main purpose of pursuing the IoT approach is to help people live and work smarter, as well as gain complete control over their lives. In addition to the IoT enabling the use of smart devices to automate homes, it is essential for businesses because it can provide them with a real-time perspective on how their systems really work, delivering insights into everything from the performance of machines to supply chain and logistics operations. The IoT also has huge potential to assist medical professionals to monitor and follow up patient health. For example, sensors could be connected to a patient's body at home or in another setting outside of a medical center. In the case of a patient with a heart problem, the signals received from the sensors could be used to monitor any deviation from the expected heartbeat values or signals of that patient, this would allow doctors to follow up the patient remotely and take any necessary action quickly that could potentially save the patient's life. The key benefits of using the IoT are the ability to access information from anywhere at any time on any device; improved communication between connected electronic devices; time and cost savings in transferring data packets over a connected network; and improving the quality of services by automating tasks and reducing the need for human intervention.

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For the successful deployment and management of an IoT-enabled application such as an ECG monitoring system, cloud computing is indispensable because it offers high computational capabilities as well as large storage capacity. Advanced IoT techniques combined with the cloud allow ECG data to be stored and analyzed effectively and efficiently. With the aid of an IoT-cloud, computation-intensive data processing and analysis tasks can be carried out in powerful servers, which greatly eases the burden on smart devices [8]. An IoT-cloud for ECG monitoring usually consists of two functional modules, i.e., data storage and data analysis. After the monitoring system has obtained a large amount of ECG data through the ECG sensor boards, the IoT-cloud needs to provide a fast and convenient way to store these data in a database, as well as a means to detect and display the ECG signals when required. Therefore, in the proposed architecture, the IoT-cloud consists of the following components: a storage server including a storage server (MySQL database) and a HTTP web server, which is able to accept the user's responses and respond accordingly. These components are described below.

1) Servers

Two types of servers that have various functionalities are used in the IoT-cloud, i.e., a storage server and a HTTP server, as shown in Fig. 2 above. The development of virtualization technologies means that these servers can be established on virtual machines, which enables optimal use of physical resources, such as central processing units, memory, etc. The servers that are deployed in the IoT-cloud for use by the ECG monitoring system are described in the following:

- *Storage server*

The ECG data plays a vital role in the early calculation and diagnosis of heart diseases. Thus, in the context of this work the timely and reliable storage ECG data is one of the most significant functions of the storage server in the IoT-cloud. In the proposed architecture of the ECG monitoring system, the ECG data obtained by the ECG sensors is stored in a MySQL database, which is currently the most popular open-source relational database available. As shown in Table 1 below, the ECG data is stored in the storage server on the IoT-cloud, in a MySQL database named ECG_Monitor. This database is composed of three tables: Patient, ECG_info, and ECG_Values. The Patient table contains the key information about the patients. It consists of three fields that are self-explanatory: PatientID, PatientName, and Pa-tientAge. The ECG_info table stores all the ECG information for the patients. In the ECG_info table, ID_info refers to the ECG identifier, ECG_Timestamp refers to the ECG timestamp, ECG_Duration refers to the ECG duration in minutes, No_of_Beats refers to the total number of heartbeats, No_of_Normal refers to the number of normal heartbeats, No_of_Abnormal refers to the number of abnormal heartbeats, and PatientID refers to the patient identifier. The ECG_Values table stores all the ECG values that are transmitted by the AD8232 heart monitor sensor to the IoT-cloud. In the ECG_Values table, ID_info denotes the ECG identifier, PatientID denotes the patient identifier, X de-notes the x-axis for the ECG chart (incremental values), and Y denotes the ECG values obtained from the ECG AD8232 heart monitor sensor.

- *HTTP web server*

Based on the traditional request-response mechanism, the HTTP web server is able to accept the user's responses and respond accordingly. In order to access ECG data, the user sends a GET request to the IoT-cloud via a URL. Then a file written in HTML is transmitted to the browser through the HTTP protocol. The browser is able to convert the HTML file into a user-friendly GUI for the user to securely log into the server. After successfully gaining access, the user is able to view a real-time ECG monitoring website. This website displays all the stored data on the patients and their ECG data in the form of tables and charts. The webpages that can be accessed by the user are explained in more detail in subsection (3).

Table 1. Tables in the ECG_Monitor DB scheme: (a) Patient, (b) ECG_info, and (c) ECG_Values

(a) Patient Table		
PatientID	PatientName	PatientAge
1	Sami Ali Jaberi	55
2	Salem Mohammad Omari	60
3	Ibrahim Bader Al-Faisal	64

(b) ECG_info Table						
ID_info	**ECG Timestamp**	**ECG Duration**	**No of Beats**	**No of Normal**	**No of Abnormal**	**PatientID**
100	2020-08-12 12:00:00 am	5 min	430	427	3	1
101	2020-08-12 04:00:00 am	5 min	400	371	29	1
102	2020-08-12 10:00:00 am	5 min	370	355	15	1
200	2020-08-13 02:00:00 am	5 min	340	288	52	2
300	2020-08-14 10:00:00 am	5 min	332	299	33	3

(c) ECG_Values Table			
ID_info	**PatientID**	**x**	**y**
100	1	1	235
100	1	2	-21
100	1	3	-103
100	1	4	-97
100	1	5	-93
100	1	6	-105

C. *ECG Monitoring GUI*

The ECG monitoring GUI is utilized for the purposes of data visualization and management. It provides the user with easy access to the data in the IoT-cloud. A user with the necessary authorization, such as a doctor, can log onto the cloud to acquire visualized ECG data in real time for a certain patient. Generally, the user can visualize ECG data through two kinds of GUI: a mobile app or webpages. A mobile app can provide an immediate response to user input, while webpages are more convenient in terms of maintenance and upgrade.

In this work the real-time ECG monitoring GUI is in the form of a website that is designed and programmed using PHP programming language, as shown in Fig. 5 below. The website displays all the data that are stored in MySQL database (ECG_Monitor DB) on the IoT-cloud. It contains three webpages: Doctor, Patient, and ECG_Patient webpages. The doctor webpage displays the information about the patients (patient ID, patient name, patient age) who are under the care of a certain doctor, as well as a link to the Patient webpage. The Patient webpage displays all the ECG information for a certain patient, such as the ECG ID, ECG timestamp, and ECG duration, and a link to the ECG_Patient webpage. The ECG_Patient webpage displays all the patient and ECG information contained in the other two pages for a certain patient in the top portion of the webpage and provides live ECG data in the form of a chart in the bottom portion of the page. This webpage shows the ECG data that has been detected and calculated as the total number of heartbeats, number of normal heartbeats, and number of abnormal heartbeats. As this chart is live, it can help the doctor to evaluate the status of the patient when the patient is at home and needs to be followed up periodically, avoiding the need to go to a medical center, which is especially beneficial due to the current COVID-19 pandemic and the lockdown in place in many places around the world. Thus, the system can prevent the patient from becoming infected and save the patient both cost and time. This system can also give the patient peace of mind because it can alert the doctor if any deviation in the heartbeat values or signals from normal to abnormal is found. If this is the case, the doctor can select a suitable medical intervention for the patient. Moreover, in an emergency, such as a SCA, the system can be used to monitor the patient while they are in the ambulance on the way to the medical center. Thus, the doctor has prior knowledge of the patient's condition and be ready to act accordingly, not only saving a lot of time, but also potentially, the patient's life.

3. Advantages of Proposed IOT-Cloud ECG Monitoring System

Referring to the ECG signal depicted in Fig. 1 above in the Introduction to this paper, the proposed ECG monitoring system acquires the ECG signal data in the time domain detects and calculates the total number of heartbeats, number of normal heartbeats, and number of abnormal heartbeats to assist the doctor in monitoring and following up the heart health of patients and taking appropriate steps where needed. The proposed IoT-cloud ECG monitoring system has five main advantages:

A. *Portability*

The proposed system can be carried with ease and uses Wi-Fi communication; therefore it can be used in a variety of settings. As the system employs Wi-Fi, the need to use mobile apps, which are often OS-specific, is eliminated because the web-based GUI provides a versatile means of accessing ECG data that is independent of any mobile OS platform. Most importantly, the proposed system allows doctors to view and analyze the ECG signals and heart status of patients remotely. This is particularly helpful for patients living in areas who have no access to a doctor or a healthcare facility. The architecture of the proposed system is also of great benefit to patients who are being transported in a moving ambulance because doctors in the medical center can access up-to-date ECG data before the arrival of the patient and be ready to perform the appropriate medical intervention. Hence the proposed system can save a lot of time and could save life because in the case of SCA every second counts. The executable webpage for the proposed system can be found using this link: https://qtaishhospital.000webhostapp.com/

B. *Reachability*

The ECG signal data are transmitted through the Arduino with Wi-Fi shield board to a MySQL database on the IoT-cloud. The stored ECG signal data can then be displayed on the ECG monitoring website anywhere any time. Therefore, the doctor can check previous and current data on the heart condition of a patient without the need for the patient to attend a medical center for tests.

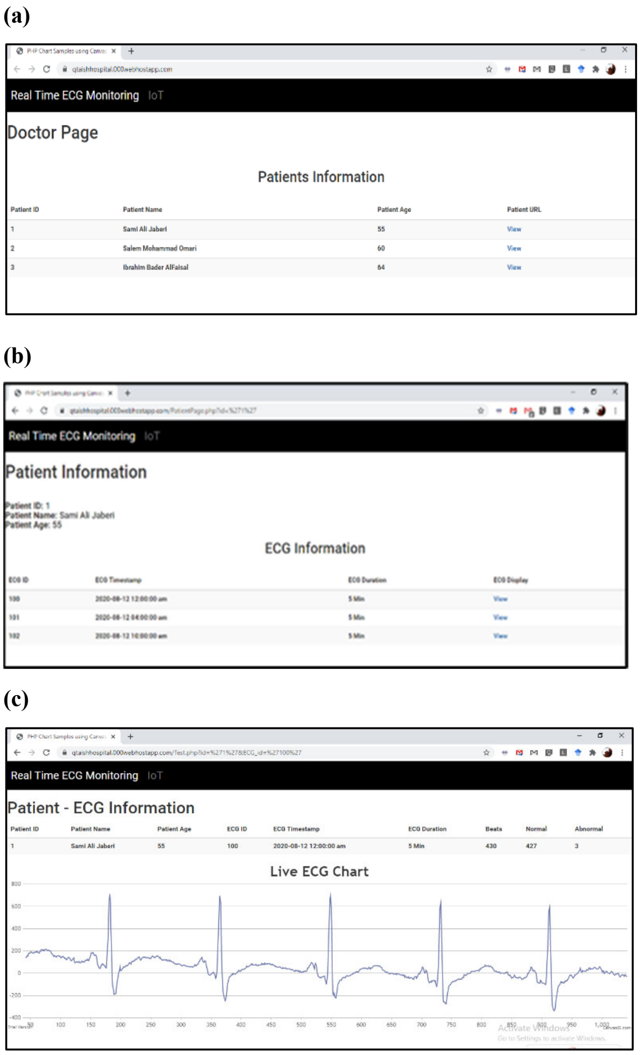

Fig. 5. Real-time ECG monitoring website: (a) Doctor, (b) Patient, and (c) ECG_Patient webpages

C. Real-time system

The proposed system uses the advantages of the cloud, which allows ECG monitoring in real time. All the ECG signal values obtained by the AD8232 sensor board are sent via the Arduino with Wi-Fi shield board to the MySQL database server on the IoT-cloud every time readings are taken. These data can be displayed on the doctor's webpage almost instantaneously. The webpage provides the doctor with up-to-date ECG data in chart form and enables the doctor to take appropriate action where needed. For example, if any deviation in heartbeat values or signals from normal to abnormal is found, the doctor can contact the patient to request that he/she visit the medical center for further tests or in an emergency arrange for an ambulance to be dispatched to the patient.

D. Simplicity

The proposed system uses the AD8232 heart monitor sensor board, which is a small device that only needs very small electrodes to record the ECG signals of a patient. This obviates the need for the patient to travel to a medical center to undergo tests on a large machine such as a fixed ECG monitor device.

4. Conclusion

This paper presented the architecture for a smart, portable ECG monitoring system based on IoT technology that was designed and implemented as a prototype. The architecture of the proposed system consisted mainly of three components: ECG sensor boards, IoT-cloud technology, and an ECG monitoring GUI. Typical ECG sensor boards, i.e., the AD8232 ECG heart monitor sensor board and the Arduino with Wi-Fi shield board, were used to measure the electrical activity of the heart with a high enough gain to get a good resolution and send the data to the IoT-cloud. Data were sent to the IoT-cloud using Wi-Fi communication, which supports high data rates and wide coverage areas. The utilization of IoT-cloud technology enabled the storage, visualization, and analysis of these valuable ECG data. While the data are stored in the IoT-cloud, the total number of heartbeats, number of normal heartbeats, and number of abnormal heartbeats are calculated and thereby predict the presence of heart conditions. This feature of the proposed system can help doctors to evaluate the heart status of patients in a timely and accurate manner and consequently choose a suitable medical procedure. The IoT-cloud was implemented on two servers, i.e., a storage server and a HTTP web server. Hence the developed architecture eliminated the need for mobile apps because the web-based GUI provides a versatile means for users to access ECG data independent of any mobile OS platform.

Despite the obvious potential of the proposed system, further studies on intelligent, small-scale, long-term ECG monitoring are still needed to enhance performance. For example, the accuracy of the diagnostic results based on the ECG signals needs to be improved to provide a more reliable output upon which doctors can base their disease diagnoses. Nevertheless, it is believed that a long-term and us-er-friendly ECG monitoring system such as the one proposed in this paper can make an important contribution to mitigating existing healthcare problems through more effective, long-term remote monitoring and thereby enable follow-up and intervention. In addition, it is evident that such a system can help in the early calculation of abnormalities in the heart that are indicative of a range of cardiovascular diseases and thus assist in the prevention of serious consequences such as cardiac arrest and even death.

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