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Digital Health: An IoT-Based Robust Framework for Remote Patient Monitoring

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Abstract

The lack of proper medical care, as well as the problem of older patients or people with motor disabilities, require the intensive use of the remote patient monitoring solutions. In this paper, we will introduce the DigitalHealth solution which is an extensive IoT-based system to effectively track the health of patients in real-time and offer powerful responses to it. The structure comprises of Perception, Network, and Application layers. Critical health data like pulse rate, body temperature, blood pressure, oxygen saturation, etc., are perceived at the perception layer over smartly integrated sensors and wearables via Arduino Uno. The sensor data was stored in real time at the cloud storage platform of AWS, which was insecurely transferred. Addition of high networking features in the Network layer provides reliable data transmission. An easy-to-use Android application will inform the healthcare professionals with graphical indications of the health parameters of the patient to make informed decisions. The suggested architecture will significantly decrease the number of visits to the hospital and the cost of the medical services relied on through the use of the IoT technology and health wearables, as well as will improve accessibility and affordability. It is a holistic solution that demonstrates the possibility of a higher level of results in remote patient monitoring, combining cloud computing, IoT, and mobile applications.

Keywords	DigitalHealth; Remote Health Monitoring; Internet of Things (IoT); Fog Computing; Cloud Computing; Wearable Devices

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1. Introduction

The Internet of Things (IoT) is a way to connect users, devices, and services collectively referred to as "things." The IoT intends to promote the exchange of information and to carry out monitoring, control, and calibration of devices worldwide. It provides technologies and supports solutions suitable for various application areas, such as smart metropolises, circulation overcrowding control, traffic and waste management, monitoring of structure, safety control, smart digital industry, emergency response, and road services. One of the key areas of applications is IoT-enabled healthcare and smart digital health. Critical IoT plans allow personalized fitness plans, while other methods can control and treat chronic diseases. Similarly, it can be used to support the care of elderly persons. the IoT can make it easy to keep an eye on a patient's health, including monitoring and control over treatments and drugs offered by professional medical experts. In this range of applications, various medical equipment, sensors for vital body measurements, and diagnostic tools can be viewed as quick devices or objects that form the core elements of an IoT framework. Furthermore, the IoT-based healthcare domain can facilitate Computer Assisted Diagnostics (CAD) and data-driven decision support systems for medical practitioners. For example, exponential growth is observed in the number of cardiovascular diseases every year due to obesity, smoking, alcohol consumption, and sedentary habits. Also, in the case of elderly patients who need health monitoring as well as follow-up on a regular basis, patients with disabilities, or those living in remote areas where there are no nearby healthcare units and it is hard for them to reach healthcare centers in case of emergency medical situations, or insufficient and inadequate health services in the underdeveloped or developing countries, it is much needed to incorporate modern digitals tools and technologies and provide them with low-cost effective health services .The benefits of IoT-based health services and remote patient monitoring are many folds as it diminishes costs, enhance the quality of life, and aid in better understanding and assessment of patients. Moreover, the IoT-enabled healthcare framework can achieve better interactions of healthcare professionals with patients, their attendants/guardians, clinics, and medical institutions. Finally, state-of-the-art healthcare systems powered by the tools and technologies offered and supported by IoT and cloud computing are expected to decrease the impact of chronic and infectious diseases in society and enable early detection and decision-making in real-time emergency situations proactively. Keeping in view the aforementioned factors, we have proposed a scalable and robust IoT-enabled cloud-based remote health monitoring framework.

The system integrates IoT devices and a cloud-based facility into our proposed architecture that supports three main layers, including perception, network, and application layers. Vital body measurements are sensed at the perception layer via IoT devices (with sensors) like pulse rate, body temperature, blood pressure, oxygen saturation, ECG signals, etc. The data acquired in real-time is securely transmitted to the cloud using API gateways through the network layer. Apart from the data transmission, the network layer is equipped with data processing, data analysis, and data storage modules that store/process data and generate alerts for health workers using intelligent algorithms and trigger alerts. At the application layer, a mobile application is developed providing the interface between data and alerts and also facilitating data visualization for patients, medical practitioners, guardians of the patients, clinics, and labs. The proposed system is

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designed to handle large-scale data by applying variable trials and applying fog computation to the data received from IoT sensors at the perception layer. Fog computing (used at the micro-controller and intermediate hub levels) applies filtering, data pre-processing, and multiplexing. Additionally, the application layer describes the doctor's perspective on the system. The major contributions and novelty of this work are as follows:

- Incorporated a layered architecture by introducing perception, network, and application layers for handling large volumes of sensor data via variable trials and fog computing.
- Development and deployment of an IoT-based robust and scalable architecture for remote health monitoring to provide healthcare facilities to elderly patients, patients with disabilities, and communities living in remote areas thus reducing unnecessary load on hospital resources such as beds and physicians.

The rest of this article is structured as follows. Section presents the related work. Section demonstrates the methodology and details of our proposed layered architecture. The implementation details are provided in Section followed by the Experimentations and Evaluation in Section. Section concludes and provides future possible directions for this research work.

2. Related Work

Internet of Things (IoT) is defined as a networked system consisting of built-in sensors, processing units, or tools that enable information collection, transmission, and processing at a distance in one form or another. it can find numerous applications in the healthcare system, and in a few instances, this involves remote healthcare, treatment, and rehabilitation. It achieves that by assigning all active resources to a network to track health conditions like detection, observation, and teleoperation through the Internet. The literature has recorded quite a number of contributions made e.g., in, the authors developed a healthcare monitoring system that reads the information on bio-medical sensors and also transmits it to the adjacent gateways where the information is further processed. They capitalized on the latest technologies and the efficiency of the system is substantial but the only flaw is the absence of security which they like to provide in the future. Nerella, Subhash, et al. had their new architecture with the addition of the IoT to the healthcare system, to monitor the critical patients in the smart setup of the intensive care unit ICU. The system provides real time recommendations and alerts and informs doctors/caregivers of the changes in the vital signs or movement of the patient. Furthermore, the scheme has drastically changed the ecological parameters and acquired the software and hardware resources needed in the Kinect surroundings. The system will however need to be upgraded by introducing new sensors to compute pressure and weight. Besides, the development of wearables has provided new opportunities to facilitate the IoT in biomedical use to gain data and send it to the Internet to explore it further and make an ultimate decision. Taking into consideration various activities, the portable patient observation system may be separated into four groups based on the sensors types: bio-potential, biochemical, environmental, and motion sensors. A wearable sensor on the chest has the ability to record the heartbeat. The determination of ear lobes, wrists, fingertips etc is based on the pressure, PPG, and radio frequency (RF). Pricey gadgets are able to differentiate between variations in heart rate. The bracelet Vibrio is used to remind patients to take essential medications. In this respect, a method was suggested by Majumder et al., whereby a low capacity multi-sensor wearable device was applied to

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perform dynamic and real-time cardiac arrest analysis. It also employs ML algorithms and signal processing techniques to diagnose and give warnings against unexpected heart attack. The method suggested by Brazilian et al. involves sensors to be put in clothes and move ECG devices. It employs the nasal thermistor sensor to ascertain the rate of respiration. The sensor identifies the growth and decrease of temperature to measure the respiration. wang et al. suggested a new way of gauging the rate of breathing among asthma patients. The process utilizes the watermarking and signal enhancement technology in transmitting secure data. It is a measurement of blood pressure (BP) that is conducted through pulse rate, breathing rate and body temperature. On the same note, the authors of presented a survey of portable IoT devices to measure blood pressure, which fail to provide reliability and traceability in blood pressure measurement. In addition, the authors further mentioned that such approaches have insecure IoT frameworks as well. Moreover, the use of small sensors that can be readily and successfully incorporated into various structures is also necessary.

3. Methodology

Figure 1 This section presents a detailed description of the methodology, components, and necessary steps involved in accomplishing the system's objective. Figure 1 shows the basic workflow of our proposed system. Our framework consists of three main functional layers: the perception, network, and application layers. The perception layer acts as an interface between the patient, sensors, and IoT devices. Hence, this layer is also called the remote sensing layer. It uses IoT devices to acquire patient data (vital health signals) and send it to the cloud over the network. The network layer will be a general infrastructure of the cloud that will carry out different operations like data management, storage and processing of the information that is sent to it by the perception layer. The application layer becomes a point of interface between the doctors, clinicians, patients, and caretakers to perceive patient information, derive responses, and communicate with the system. The following subsections are a detailed description of the layers and the modules that follow.

3.1. The Perception layer

The IoT devices and sensors at the perception layer capture patient information i.e. vital health signals and transfer them to the cloud as depicted in Figure 1. The first layer receives the information of the sensors and first stores it in Microcontroller Unit (MCU) and then transmits it to the smartphone through the Bluetooth method. The smart phone has Restful API (gateway) which transfers data to the cloud further.

3.1.1. The IoT Module

The IoT device will include an arduino microcontroller with body temperature, ECG, pulse rate, and oxygen saturation sensors. It is also linked to an application in a smartphone.

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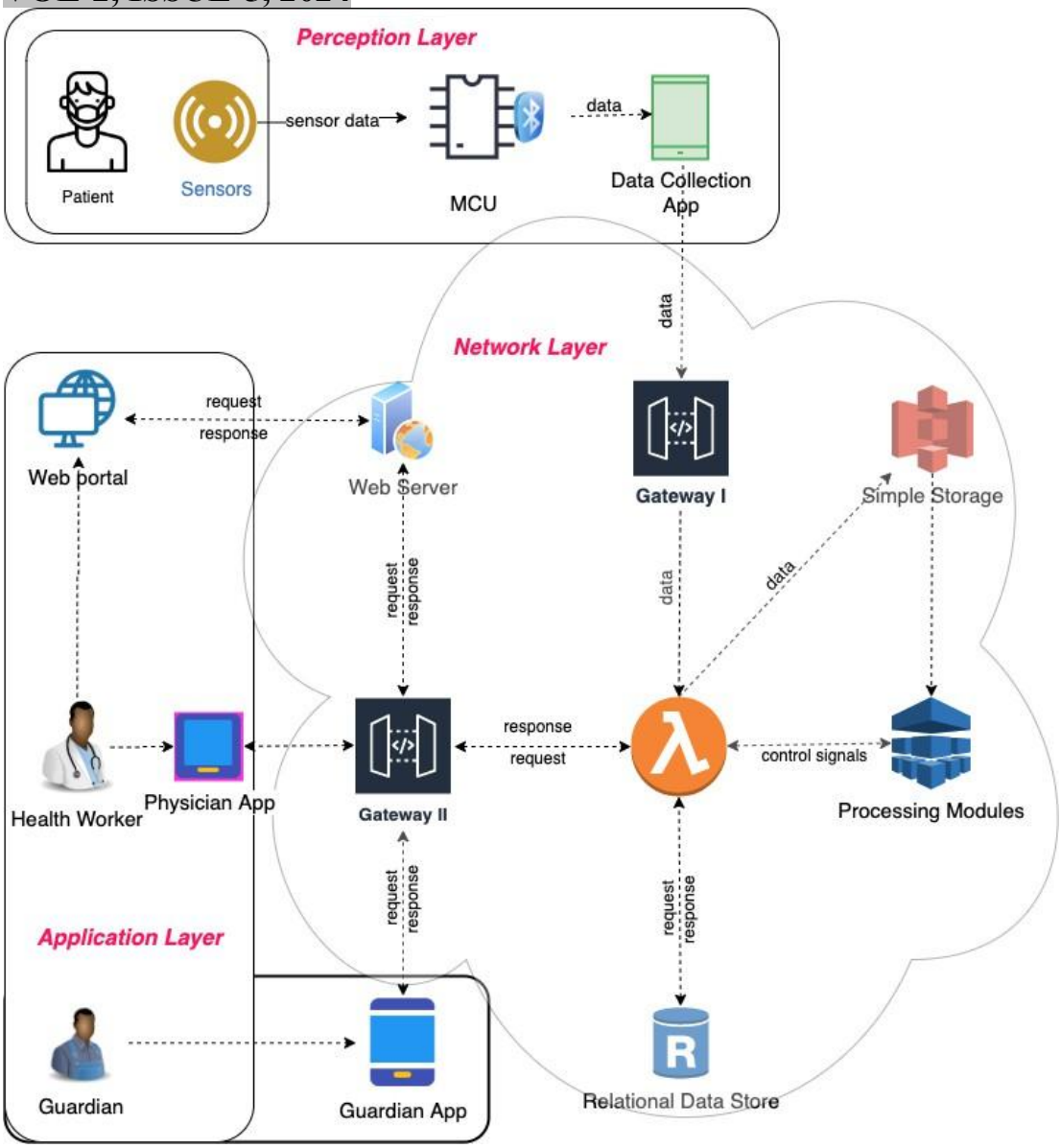


Figure 1. Block diagram depicting the data and control flow of our proposed three-layered architecture.

Nonetheless, the huge information produced by a number of sensors pose a number of challenges at the perception layer. To start with, it is hard to accommodate more sensors because the amount of data is overwhelming. Second, connected smartphones are low power devices, which have difficulties processing large volumes of data at some length of time. Finally, the large volume of data causes congestion of network and cloud gateway, as well as, reduces the cost of data processing. Our suggested system uses fog computing to overcome the issues of the large number of data at the perception layer. An example of the data collected by pulse and temperature sensors is shown in figure 2. The system captures data samples after every four milliseconds and this exposes the redundancy of data in most of the samples. As an example, the pulse has two variations in the range between 85-87 and the temperature has nine variations in the range between 80-90. Contrary to the current remote monitoring systems that use the same sample rate, we have seen that using varied sample rate to various sensors increases efficiency of the system. In this

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way, the suggested system will give weights to the sensors according to their importance. To give an example, the weights are given greater weights to ECG readings that are larger in size and change regularly than the body temperature. This means that more weightier sensors are read by the system as compared to lightweight sensors. Moreover, we see that sensor data usually have redundant data. The suggested system employs the concept of redundancy reduction by calculating the mogs on the microcontroller level to enable the system identify redundant data. When sensor data sample is similar to the one received, it is not transmitted to the smartphone but rather it is discarded.

temp	pulse	time
80	87	2023-04-10 16:20:10
80	87	2023-04-10 16:20:12
80	87	2023-04-10 16:20:16
80	87	2023-04-10 16:20:20
80	87	2023-04-10 16:20:23
80	87	2023-04-10 16:20:27
80	85	2023-04-10 16:20:31
82	85	2023-04-10 16:20:34
84	85	2023-04-10 16:20:38
86	85	2023-04-10 16:20:42
87	85	2023-04-10 16:20:45
88	85	2023-04-10 16:20:49
89	85	2023-04-10 16:20:53
90	85	2023-04-10 16:20:56

Figure 2: Sensors data recorded using the IoT module. The data shows redundancy in values of body

3.1.2. The Smartphone App

To send the data obtained through sensors by the IoT module to the network layer to be further processed and analyzed, the latter is first delivered to the smartphone application by Bluetooth. To overcome the effects of the large content of data on the system, we have proposed the inclusion of second-level fog computation on our system. This will entail processing the information at the smart phone and establishing whether urgent transmission to the cloud is essential. The data is stored locally in case it is not necessary. As an example, under 97 to 99 degrees of body temperature is regarded to be safe and fast transmission is not necessary. In addition, the smartphone module can be processed locally, which makes multiplexing easier, thereby decreasing the load on the cloud gateway. Also, the smartphone offers the ability to be connected or not, which allows managing the flow of data between modules. The functionality of our proposed system to process large data volumes by using different frequencies on the sensors and filtering redundant information at both the microcontroller and smart phone levels will successfully support more sensors

3.2. The Network Layer

This layer also known as the cloud layer, facilitates data management, collection, and processing.

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The layer receives data from the perception layer and sends it to storage after initial processing. This layer consists of several modules that are discussed as below.

3.2.1. API Gateways for Incoming IoT Data

In the AWS cloud, health monitoring systems have two choices for receiving data from the smartphone application. One choice is to use a protocol known as message queuing telemetry transport (MQTT). MQTT is also called a lightweight publish-subscribe network protocol, which enables the system to transmit messages among IoT devices. The second choice is to use the lambda event service. The proposed system chooses event service instead of MQTT because it allows the system to manage efficiently the processing of received data and the subsequent calls to microservices in the AWS cloud. It also facilitates the proposed system to establish a robust authentication scheme. Upon acceptance of data on the event server, the system authenticates and verifies data using the Jason Web token (JWT). We believe that verifying data sources is essential in telemedicine, particularly for healthcare information. Therefore, if necessary, the system applies an additional layer of security using encryption technology. Upon data verification and validation, the system carefully checks the reading to determine critical situations that require emergency medical care. Hence, if necessary, it notifies health representatives and caretakers. In all other cases, it sends the data to information storage.

3.2.2. Cloud Storage

Our proposed framework categorizes cloud storage space into Relational Data Storage (RDS) and non-relational data storage. It executes relational data storage by employing RDS instances, which supply the patient's medical record and current situation. Thus, it keeps all recent analyses in RDS. Moreover, the system implements non-relational storage by employing a simple storage service (S3) and stores a large volume of data from the IoT module. Also, the data from this storage is retrieved when needed.

3.2.3. Post Processing Modules

The refined data forwarded by the mobile application to the cloud is processed and analyzed here. The main steps and operations performed on data in this module include but are not limited to simulated intelligence, ML algorithms, and visualization tools. Such modules help physicians to carry out advanced/assisted diagnoses and provide medical decision support to them. The proposed system offers specific primary visual effects and comments to show the effectiveness of our framework.

3.2.4. API Gateways for Application Data

To simplify communication between the Application layer and the Network layer, we have used API gateways. Again, the suggested approach ties the lambda function to the gateways and uses JSON Web Tokens (JWT) to authorize the connection with the Application layer. It invokes a relevant service in response to a specific request after successful authentication.

3.3. The Application Layer

The interface which allows doctors and health workers to use the system together is termed the application layer. It contains a web-based dashboard, a physician's smartphone application, and a guardian's smartphone application. Using these interfaces, users can obtain real-time information about the patient's condition. Medical staff also use it to view data visualization and perform AI and ML-assisted diagnoses. Detailed information on this layer is given below.

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3.3.1. Physician Smartphone App

This application serves as the interface between the system and doctors. It enables doctors to get real-time information about the patient's health status. The application also facilitates AI and ML applications to visualize or trigger data on patient information.

3.3.2. Guardian Smartphone App

The app is an interface that allows the Caretaker/Guardian of the patient to obtain real-time information about the patient's health. If the patient needs immediate attention, the guardian is notified via this application using an alert generated by the system.

3.3.3. Web Dashboard

In order to monitor the patient's health status in real time and automate the diagnosis and response to the patient's condition, the dashboard provides healthcare professionals with an interface to interact with the system. Similar to the physician's application, it enables computer-aided diagnosis and data visualization. Additionally, this application allows doctors to conveniently analyses and assess their findings stored in the cloud and promptly notify the guardian.

4. Implementation

The steps involved in the implementation process adopted, integrating several services, tools, and packages for IoT-based remote patient monitoring into the healthcare ecosystem, ensure a robust and efficient framework. A brief description of each layer is as follows. As shown in Figure 3, the patient

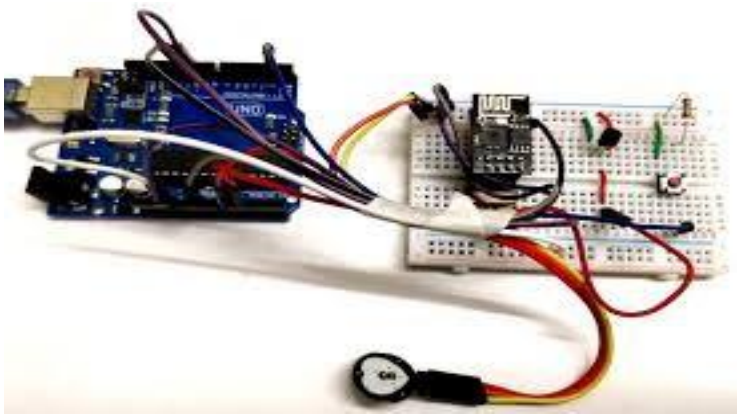


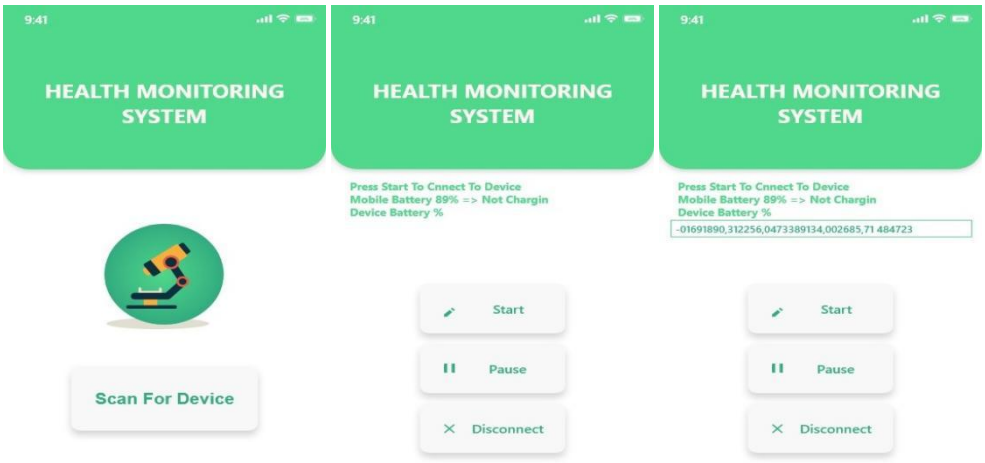
Figure 3: The IoT module showing Arduino UNO interfacing with pulse and temperature sensors data is recorded in the IoT module equipped with different sensors for vital body measurements. The IoT module consists of a UNO board and temperature and pulse sensors. The module assigns a unique identifier (Card ID) to each IoT card, which allows it to distinguish between different cards and identify the patient on the distribution board. We have used the LM35 chip to record the temperature, the B269 sensor to record pulse rate, and AD8232 ECG sensor. Moreover, we installed a Bluetooth module (HC05) on the UNO card to enable communication between the smartphone application and the Arduino module. The source code of Arduino is programmed in C language and uses the built-in ADC to read data from multiple sensors. After pre-processing and multiplexing, the Android smartphone app obtains IoT-enabled data from the Arduino's microcontroller and transmits it to the cloud. The application is developed in react-native, as shown in Figure 4. The screen displays provide options for connecting to the IoT device and

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also visualizing the incoming data. We configured the network layer in AWS Cloud and implemented the API Gateway via the lambda function. The lambda function is an event-based and serverless platform. Using this platform, the proposed system executes code remotely when an event triggers and manages the required resources automatically. Moreover, it employs Aurora on the RDS instance to develop relational data storage.

Figure 5 shows an instance of patient data, which is stored in AWS S3. In addition, we used JavaScript to implement the visualization algorithm. The Application layer of the proposed system consists of a guardian application, a physician application, and a web-based dashboard. All the mentioned interfaces are created using the react-native framework. Moreover, the application layer is also equipped with the functionalities to send alerts regarding patients' status using AWS simple notification services (SNS).



(a) **(b)** **(c)**

Figure 4. The smartphone app for data collection. (a) scanning for available IoT device using Bluetooth, (b) shows options for starting/pausing and disconnecting the IoT device, (c) shows the receiving of values from IoT device after being connected.

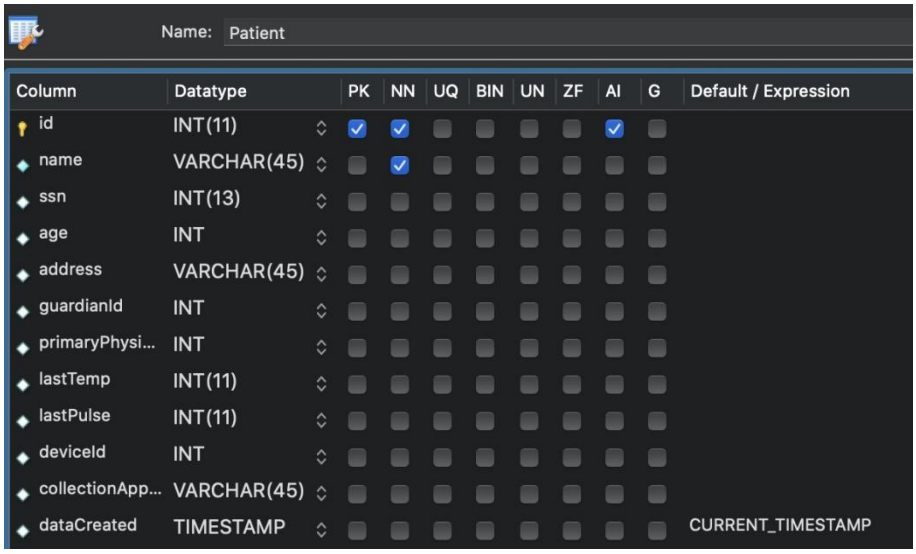


Figure 5. The metadata of patient table.

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5. Evaluation and Discussion

5.1. Experimental Setup

This section presents the testing of our remote patient monitoring framework and evaluates the handling of large amounts of data. We used different sensors (for body temperature, pulse rate, oxygen saturation, and ECG), as shown in Figure 3. Our proposed system captures data at a variable rate (10 and 20 samples per second) and transmits via Bluetooth to the Android data collection application. The data captured at the perception layer is forwarded by the application layer to the AWS cloud for further processing and analysis. The guardian and physician applications facilitate real-time monitoring of the patients by visualizing the processed data. Our proposed framework is able to record patient data comprising of vital body readings via IoT module at the perception layer, reducing the volume of data through variable sampling frequencies and forwarding it to the cloud using the network layer, the data processing and analysis are performed at the cloud and the real-time results are visualized at the application layer to both medical practitioner and the caretaker of the patient.

id	patientid	temp	pulse	dateReceived
1	1	82	88	2023-04-10 16:20:23
2	1	81	86	2023-04-10 16:20:32
3	1		88	2023-04-10 16:20:35
4	1	84		2023-04-10 16:20:43
5	1		86	2023-04-10 16:20:53
6	1		87	2023-04-10 16:20:59
7	1		86	2023-04-10 16:21:11
8	1	87	87	2023-04-10 16:21:14
9	1	90		2023-04-10 16:21:17
10	1	NULL	83	2023-04-10 16:21:22
11	1		86	2023-04-10 16:21:43
12	1	88	84	2023-04-10 16:20:51
13	1		85	2023-04-10 16:21:53
14	1	92		2023-04-10 16:22:15
15	1	93		2023-04-10 16:22:22
16	1		86	2023-04-10 16:22:32
17	1	91	85	2023-04-10 16:22:43
18		87		2023-04-10 16:22:56

(a)

	id	patientid	temp	pulse	dateReceived
	1	1	80	87	2023-04-10 16:20:23
	2	1		87	2023-04-10 16:20:27
	3	1	81	86	2023-04-10 16:20:29
	4	1		88	2023-04-10 16:20:32
	5	1	82	88	2023-04-10 16:20:36
	6	1		88	2023-04-10 16:20:39
	7	1	82	86	2023-04-10 16:20:43
	8	1	NULL	85	2023-04-10 16:20:47
	9	1	82	85	2023-04-10 16:20:49
	10	1	NULL	86	2023-04-10 16:20:51
	11	1	87	87	2023-04-10 16:20:56
	12	1	NULL	87	2023-04-10 16:20:58
	13	1	90	87	2023-04-10 16:21:03
	14	1	NULL	83	2023-04-10 16:21:05
	15	1	90	86	2023-04-10 16:21:07
	16	1	NULL	86	2023-04-10 16:21:13
	17	1	88	84	2023-04-10 16:21:16
	18		NULL	85	2023-04-10 16:21:20

(b)

Figure 6. The pulse and temperature data collected using IoT device. (a) when different collection frequencies for reading from sensors, (b) reduced data after removing repeated readings.

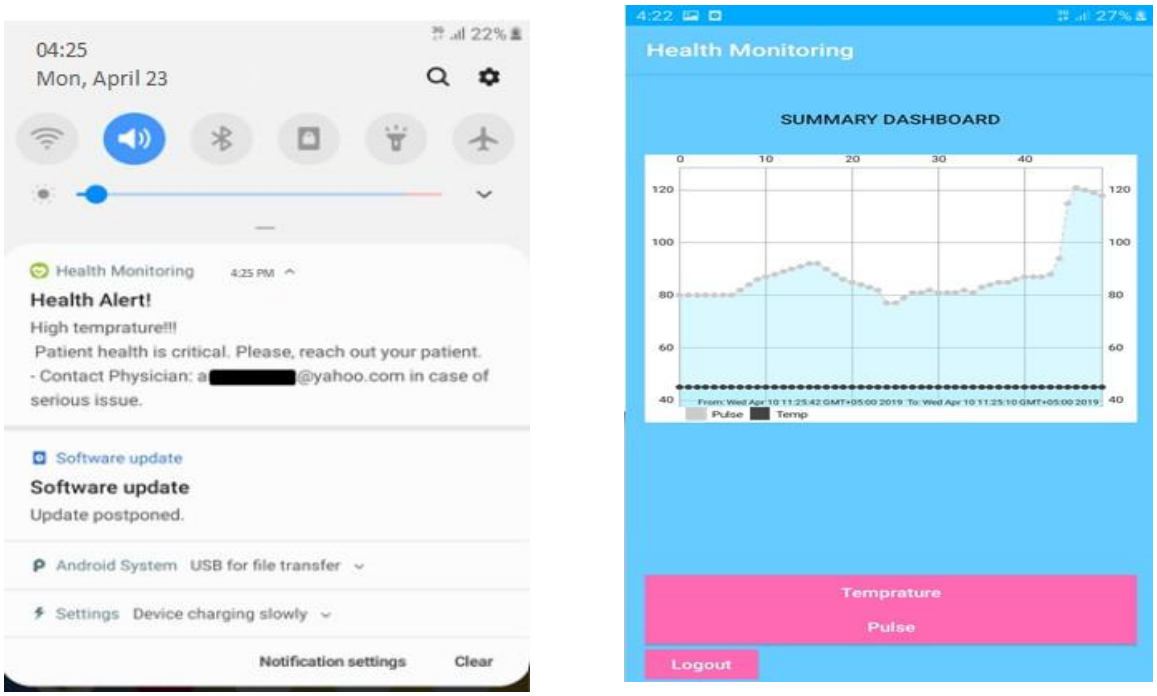
5.2. Results

Figure 6(a) shows that the IoT module records body temperature and pulse. Missing temperature readings indicate that data is recorded at varying frequencies. Applying different sample rates, it is observed that the amount of data is reduced by 25%. Figure 6 (b) shows that applying the fog calculation at the microcontroller reduces the data volume by 20%. Figure 4 shows that the data collection Android application productively reads data from the IoT module. In addition, it applies multiplexing to get ready for larger data collection and keep away the network from throttling. The data collection app invokes API calls to collect patient health data and sends it to the cloud with a unique card ID. However, multiplexing can be adaptive, which depends on the significance of the received data

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and the bandwidth of the network. We believe that other fog calculations can be helpful to conclude (notifications, alerts) at this level. The inbound data cloud gateway successfully reads the data and generates an alarm, as shown in the Guardian application in Figure 7 (a). The figure shows that the API call is connected to an oxygen function formed on the AWS cloud. It is also observed that the lambda function regains information from invoking API calls. Upon information accessibility, the lambda function uses card ID as a primary key to recognize the patient and obtains information from the interpersonal data store. Following patient identification, the lambda function operates two primary procedures on the patient's data. Firstly, considers different health constraints, it analyzes the data for specific limits. If the patient's health is crucial, the lambda function uses the SNS application to trigger the corresponding guardian and physician alarms. Secondly, the SNS application connects to Firebase Cloud Messaging. This shows the ability of the lambda function to reprocess the received data and generate alerts. The guardians and physicians receive alerts on smartphones with fixed



(a) **(b)**

Figure 7. The apps at application layer. (a) guardian app showing a health alert, (b) physician using his app for visualization. application dashboards. Moreover, it shows the alerts in the announcement panel, and their main concern is the place too far above the ground. Guardians and physicians ask to review the patient's medical history and view it to make it more comprehensible, as shown in Figure 7 (b).

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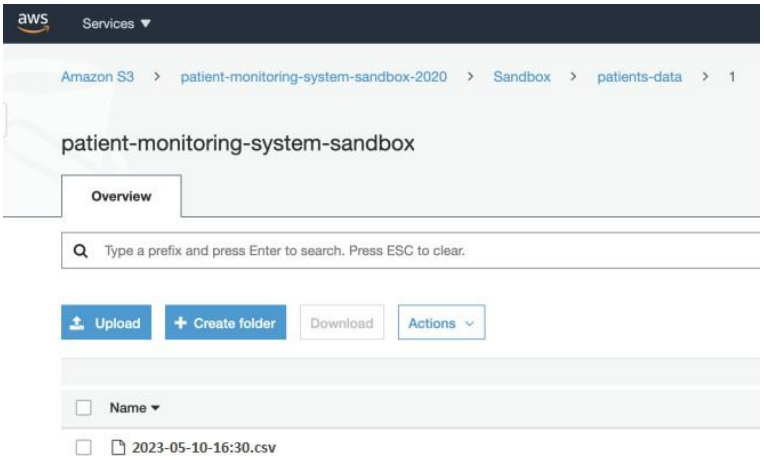


Figure 8. IoT data stored in S3.

The data is pre-processed and stored in S3, as shown in Figure 8. After postprocessing, the system stores the update in RDS.

6. Conclusion and Future Work

This article discussed in detail a robust framework for remote patient monitoring using an IoT-enabled fog computing paradigm, showcasing the implementation of our proposed layered approach for efficient data collection and analysis. The integration of various sensors, including temperature, pulse rate, oxygen saturation, and ECG sensors, has allowed for the accurate recording of patients' vital signs. Using the strength of IoT, the information that is registered is automatically relayed to the cloud to be processed to allow real-time monitoring and analysis. In addition, the current research has assisted in the creation of mobile and web applications that allow physicians and caretakers to monitor the state of patients remotely. The applications are easy to use to browse and analyze the information gathered and provide crucial information regarding the healthcare of the patient. Additionally, the applications have smart algorithms that can send alerts and notification messages timely in emergency cases to enable quick medical response.

Future Work

Although the study has contributed to improved developments in the IoT-based remote patient monitoring, the field can be further developed in a number of ways. To begin with, calibration and validation methods like precision and consistency of sensor data would improve the accuracy and reliability of the sensor data. As well, by including the use of machine learning and artificial intelligence algorithms, it is possible to have a more advanced analysis of patient data, including the recognition of patterns and anomalies. This would allow identifying the risk of severe conditions early and predicting possible health threats, which would result in proactive and individual healthcare measures. In addition, the aspects of security and privacy of the IoT system in remote patient monitoring are to be paid constant attention. To prevent unauthorized access and cyber threats of sensitive patient information, it will be necessary to improve data encryption, access control systems, and safe communication systems. Moreover, it would be beneficial to broaden the context of the research to a bigger population and various medical conditions to have a more in-depth insight into the practical implications and benefits of remote patient monitoring made possible through IoT. To sum up, the stratified design of the current research article and the use of different sensors and creation of convenient applications can be seen as a major addition to the field of IoT-based remote patient

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monitoring. Further investigations and innovation in this area promise to revolutionize the healthcare delivery system and make it more effective in terms of patient outcomes and effective medical treatment that is both proactive and personalized.

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