IoT and Smartphone-Based Remote Health Monitoring Systems

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Abstract

As people age, their body tissues and organs begin to fail. This causes a number of diseases that can quickly destroy a person's life. Thus, as long as they are alive, daily or weekly monitoring of the physiological body is an issue. To do this physically by visiting a hospital can be very difficult. IoT and smartphone-based systems are one subset of new technologies that focus on shifting in-hospital treatment to out-hospital treatment, therefore avoiding having to go to hospital to know his/her health status physically. The system collects real-time data from the patient's body without burdening their daily activities. The practical implementation of the system is improved by taking five patients as a sample, and data acquired from each sensor is analysed by calculating the error rate. The advancement of information communication and technologies in mobile technology not only provides a calling service but provide services in health monitoring activities. This paper describes how advanced smartphones and wearable sensors play important functions in remote health monitoring. Wearable sensors can obtain data from the patient's body, while smartphones can obtain the patient's parameters (data) from wearable sensors through Bluetooth communication technology, and then send the data to a database (Cloud) through a wide area network (WLAN) technology for future access.

Keywords

IoT • Smartphone • Wearable sensors • WBAN • Physiological parameters

1 Introduction

Internet of Things (IoT) technology using mobile smartphones plays many tasks around the world at this time. The advancement of these technologies is not limited to a number of specific areas. It is possible for health care providers to deliver remote health monitoring activities by using modern technology IoT (wearable sensors + communication modules like Bluetooth and WLAN) and mobile smartphones (Lomotey et al., 2017). This means health and medicine collage is an area where IoT technology play a great role (Pang, 2013).

Researchers have shown (O'Neill & Peoples, 2017) that IoT plays a great role in smart cities, traffic congestion, waste management, structural health, security, emergency services, industrial control, and health care. IoT should be available over the entire country. With IoT technology unconnected things can be connected to each other for the processing and completing of tasks: sending, receiving, processing, storing, securing. In the IoT general concept, visible and invisible objects are not simply objects but smart objects. Not all objects establish communication with each other without IoT technology, and the concept is much greater than other technologies because it is a domain of all fields, include wireless networks: RFID, WLAN, LAN, Bluetooth, etc., machine learning, Cloud technologies and so on.

The traditional health monitoring systems require users to visit medical care centers and to get balanced treatments. This is especially so for rural populations. In urban and rural areas, accessing medical health care physically consumes many resources—such as time and budget, and also faces additional problems while accessing.

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P. K. Singh et al. (eds.), *Innovations in Information and Communication Technologies (IICT-2020)*,
Advances in Science, Technology & Innovation,
https://doi.org/10.1007/978-3-030-66218-9_28

As some researchers (Islam et al., 2015; Rahmani et al., 2015; Sebestyen et al., 2014) have said, health and medicine application is a place where IoT technology can be applied to many services providing monitoring and processing functions. The new system developed from the IoT and mobile computing will perform a continuous remote monitoring of the patient, highlighting vital signs effectively while consuming fewer resources (Wood et al., 2008). To remotely know the health condition of users, the sensors we use have ability to provide information frequently (Krish et al., 2011). IoT and mobile-based health care systems provide remote health monitoring, store recorded data, establish communication with health care givers and access medical health centers. However, the follow-up date will be established with specialists and patients, for giving and receiving treatment after the patient's vital signs are collected and processed (Yan et al., 2010).

In this study, we will look at some of the physiological sensors worn by the user which able to collect patient vital sign. These different sensors: ECG, body temperature and pulse heart rate sensors are comfortable and easy to wear and use (Lee & Chung, 2009). These sensors collect physiological data and forward values to the Arduino microprocessor. Smartphones are used to show the results of the processed gathered data from the microcontroller and then send it to a health care database storage and an authorized person for further processing. Before using such devices, knowing their advantages, disadvantages, battery life time, availability and cost must all be considered.

The developed system in this paper performs the following functions in the health and medicine departments:

1. The system provides real-time data and feedback; it means that at the same time that wearable sensors obtains vital signs from patients, the next process is based on values compared with the threshold values; normal physiological patient values are displayed from a local database which is an Android built-in database, while in case of abnormal vital signs, the system will display alert dialog messages to patients and send these to a remote server to be accessed by an authorized body.
2. The system provides AES security algorithms to protect each patient data from theft.
3. The system uses Bluetooth wireless communication to send and receive information—RFCOMM is the Bluetooth wireless communication protocol.
4. The system provides permissions to ensure who is authorized for accessing patients' data.

2 Problem Statement

In the current health providers' departments, the system they are using is uncomfortable for both patients and health providers. In a greater number of health providers, beyond giving real-time treatment it is a burden for data storing and accessing. There are more people who are discharged from health centers for getting real-time services. To get services for their health case status, they have to pay out expensive money, they are queued for a long time, they face shortage of commitment and inadequate medical facilities and professionals to provide patients with intensive care in emergency units and other healthcare departments.

These listed problems lead to:

- a health care system that does not support the easy monitoring of the health of patients;
- puts the burden on patients to make their treatment and to return for follow-up visits;
- find and pay for transport;
- high costs incurring.

Moreover, in developing countries, in rural areas, there is no system that gives a solution for solving these problems and monitoring self-health remotely.

3 Related Literature

3.1 Sensors and Wearables

Wearable sensors are electronic devices that any user can wear on their body and are capable of doing expected processes in convenient ways. Recent advances in security, industries, health, home life, microelectronics and data analysis techniques have been possible for using wearable technology to achieve more benefits and a health outcome. In the past years, the size of health care monitoring electronics used in medical centers made them too difficult to use. In recent years, such difficult electronics have been replaced by wearable sensor devices to gather human physiological data, providing strong security, improving human life style and to gathering movement data. Now, wearable sensors can now be deployed in digital health monitoring systems with circuits, wireless data communication protocols, and microcontrollers.

In the mid-2000s, wearable sensors, watches, clothes, shoes, umbrellas, etc., with wireless communication technology are fully integrated as a complete device used in medical (hospitals) for monitoring medical care.

Advanced wearable technology used to collect and measure the physiological signals and human movement has the potential impact on physical medicine and rehabilitation (Bonato, 2005).

Researchers have (You et al., 2017) developed mobile-based physiological data monitoring systems that perform monitoring and analysis of tasks regarding human physiological vital signs value. The system combines the wireless communication technology and wearable sensors worn on the human body to obtain physiological data. The system performs classification and analysis activities for individual patient records and stores it from where authorized persons are able to access the data for future tasks. The main problem of this system is delay time during data classification and analysis.

Researchers (Kantoch, 2013) also developed a system for patient management in medical centers. The system can transfer data via Bluetooth technology and sensors which patients wear on their body to obtain physiological data. For future purposes, data will be stored in an external server. Physical experiments are done for a number of groups. In this experiment, the system shows 95% absolute correct value when compared to the certified medical devices.

Experimental tasks took place on the group of people after they worked any activities and the result shows 95% is absolutely correct when compared to certified medical health devices. Researchers (Kakria et al., 2015) developed real-time cardiac monitoring systems in wearable sensors and smartphones in order to monitoring cardiac patients remotely. The system acquires the patient data with a zephyr sensor and stores data in online MySQL database via GPRS, Wi-Fi, and 3G from a smartphone.

3.2 Smartphone Issues

Smartphone is a device that allows communication technology in data from sender to receiver via any devices that support wireless protocol having no fixed physical link connected. Mobile computing technology involves: mobile communication, which is any infrastructures used in communication services put in place and ensures that seamless and reliable communication is establishing or going on. These would include devices such as protocols, services, bandwidth, and portals necessary to facilitate and support the stated services. Mobile hardware is another involvement in mobile computing, which is hardware we use in wireless communication: including devices such as smartphones, tablets, laptops, palmtops. Mobile software is the third one, which is a software that run on any mobile and controls any operations going in it. Researchers (Yi & Saniie, 2013) have developed smartphone-based health monitoring remotely systems. The system involves sensors that acquire data from the human body and uses wireless communication to transferred sensed data and uses a smartphone to send data to Cloud. Researchers (Jovanov, & Zhang, 2004) developed a mobile health system which is a transition of desktop telemedicine to mobile computing to monitor human signals generated from the body. The related patient data will be stored at a remote location via a wireless transmission technique.

3.3 Safety Monitoring Issues

The advancement of wearable sensors and smart mobile phones is not limited to specific areas, it involved many areas. Some of the systems developed with the IoT technology are for safety monitoring and issuing alarm messages to a user. Researchers (Lyder et al., 2012; Lemly, 2004) are using the best technology designed for safety monitoring in hospitals. These have the ability to wirelessly relay an alarm message to the patient and to describe the clinical and demographic character of hospitals to individuals. Researchers (Lee et al., 2017) using ZigBee technology developed a smart bridge safety monitoring system on the IoT base. This system consists of: (1) sensors in the bridge; (2) communication devices which connect the bridge monitoring devices (sensors) and the Cloud-based server; (3) a database that stores bridge environment-condition data; and (4) a Cloud-based server that calculates and analyses data transmitted from the monitoring devices. This system can monitor and analyse in real-time the conditions of a bridge and its environment, including the water levels nearby, pipelines, air and other safety conditions. The detected data and images are transmitted to the server and database for users to have real-time monitoring of the bridge conditions via mobile telecommunication devices. Researchers (Jutila et al., 2014) presented a prototype wearable vest keeping the safety and wellness of children in places. The system is developed with use of Lilypad Arduino and Adafruit Flora platforms and with wearable sensors, GPS and wireless communications. The developed system gathers and picks up the children's location and has the ability to send the notification to carers.

3.4 The Power Consumption Issue

Whenever we desire to use any devices or sensors, we have to consider their battery lifetime. This is one concept that every researcher will know. Each device may consume different powers of energy while in the operation process; while some devices consume less power others consume high power. For example Bluetooth consumes low power while ZigBee consumes high power. To keep the battery life of medical sensors should be ensured during operation. Researchers (Wu et al., 2017) presented how to enhance the battery life of connected devices during operation. The system uses harvesting solar power to keep the batteries of sensors connected. After experiments have taken place, the wearable sensor devices work well when powered by the solar system. The proposed system with solar energy harvesting demonstrates that long term continuous medical monitoring based on WBAN is possible provided that the subject stays outside for a short period of time in a day.

4 IOT and Smartphone-Based Remote Health Architecture

This section studies the overall picture of the system functions, components and working flows. IoT and smartphone-based remote health systems have four functions: (i) sensing function (ii) communication function, (iii) security and (iv) storing functions. Sensing function is acquiring a set of patient physiological data with the help of worn wearable sensors. Communication function is delivering of gathered physiological data to patients directly and might be to a gateway device through transmission protocols. Security function applied on the data obtained from sensors is a mechanism employed for data protection from unauthorized bodies. Data storing function represents both local and remote server for collecting and safe data. The IoT and smartphone-based remote health monitoring architecture in Fig. 1 combines two systems, such as: WBANS and the persistent storage system.

The WBANS provides two functions, sensing patient vital sign and forwarding data to a smartphone device. Then information is stored in a SQLite database and in the remote health care storage-MySQL storage from where authorized persons access and diagnose the patient's physiological status.

The system makes it easy to acquire medical related data parameters: heart rate, body skin temperature and electrocardiograms at the same time. These parameters help to avoid, or detect, cardiac diseases such as hypothermia, fever, pathological tachycardia and pathological bradycardia with automatic feedback relying on threshold range values restricted. The system has two interfaces: the patient interface and the doctor/families' interface. The patient interface involves sensors which collect vital signal data of patients and transmit it to an Android app through Bluetooth and then forward data to a web server. To login into the web, doctors/families should have a user ID and password. Then to access and make diagnosis for patients, an authorized user can use Bluetooth ID and patient ID. Figure 1 shows the system architecture.

4.1 Wireless Body Sensor Network System

WBSNS can contain a great number of WBSN. Here, each of WBSN shown in Fig. 2 has three wireless physiological sensors which obtain patient body physiological data. Then physiological data is sent to a middleware smartphone through Bluetooth communication.

4.2 Persistent Storage System (PS)

PS is a storage system where patient-related data is held in an electromagnetic or optical form for access later. However, if a container goes to off, or crashes, the data is already stored and does not get lost. The system stores data which is sent from a smartphone via Wi-Fi in MYSQL persistent storage where an authorized person accesses the data, and also data is classified in this system. Each data sent from a smartphone should be expected under its classification.

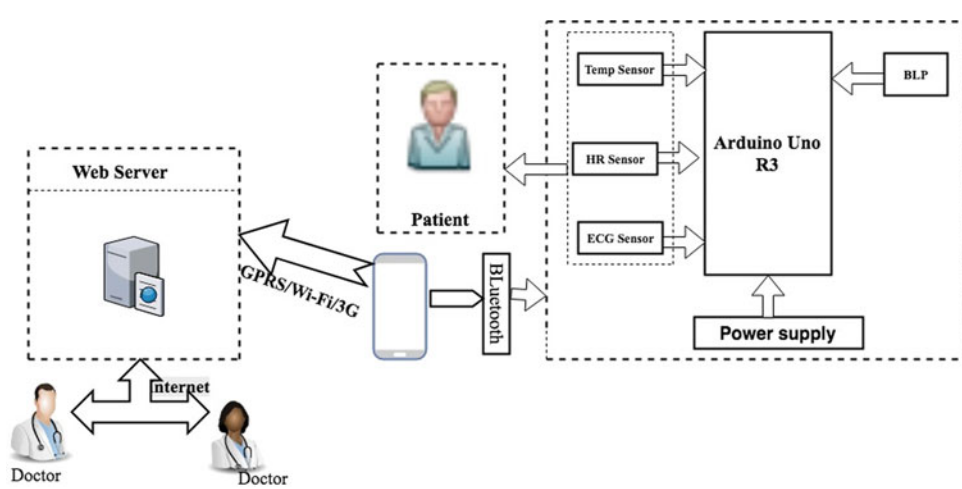
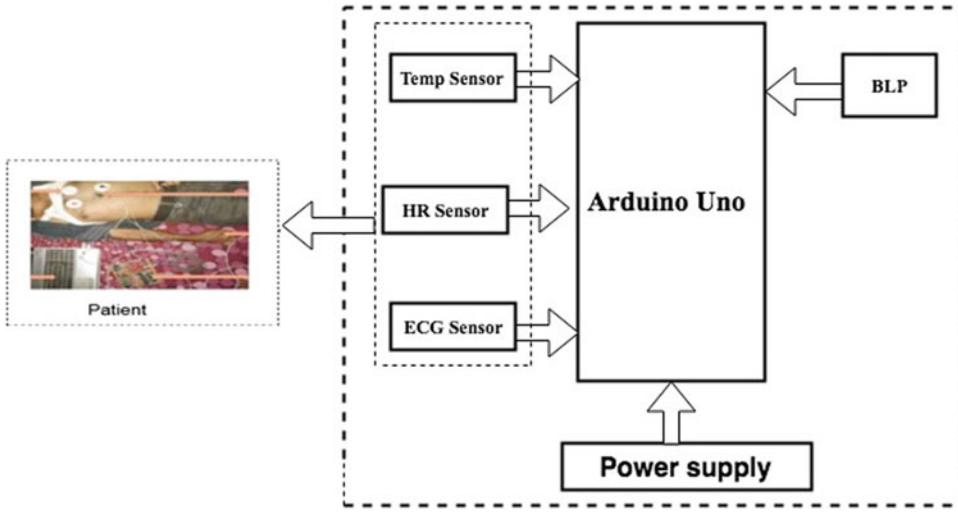


Fig. 1 IoT and smartphone-based remote health care general architecture

Fig. 2 Hardware design of WBANS



4.3 Sensors Issues

In the medical health field, the sensors are classified into two types: (i) intrusive—which measure a patient's physiological data intradiscally; and (ii) non-intrusive—which measures a patient's body data without intrusiveness. Body temperature sensors, pulse heart rate sensors and ECG sensors are non-intrusive sensors placed at the proper position for the purpose of accurately measure physiological data.

4.4 Data Security Issues

In daily life, the prevalent problem associated with enhancing data safety is data security, privacy, confidentiality, integrity and availability (Forouzan & Mukhopadhyay, 2011). The developed system also provides AES algorithms to protect the patient data from theft while storing it in a remote server. Encryption is the most important technology for protecting sensitive patient data from theft. There are two types of encryption: asymmetric and symmetric. The system focuses on symmetric encryption AES which uses the same key to encrypt and decrypt data. The comparison between asymmetric and symmetric encryption is that asymmetric encryption is not well used and not powerful enough to secure data in a database, while symmetric encryption is very common in database frameworks. Twofish, Blowfish, DES and AES are some common symmetric encryptions. The system keeps the patient-related data safe on remote sites by applying AES algorithms which provides excellent security and is more energy efficient (Daemen & Rijmen, 2002; Diffie & Hellman, 2006; Thangavel et al., 2015) (Fig. 3).

This algorithm is one type of symmetric key cryptosystem that is very easy to use and implements in security deployments. Unlike other symmetric key cryptosystems such as: 3DES, RC6 and Blowfish and all asymmetric type of cryptosystem the AES algorithm has high speed in data encryption and decryption processing. This algorithm processes a symmetric block cipher data with the three different keys length "AES-128", "AES-192", and "AES-256". In other words AES comprises three block ciphers such as: AES-128, AES-192 and AES-256. Each cipher encrypts and decrypts data in blocks of 128 bits using cryptographic keys of 128-, 192- and 256-bits, respectively. The main problem in this algorithm is exchanging the shared secret key (Mahalanobis, 2005) over an unsecure way. Figure 4 show AES design.

4.5 Configuration of Bluetooth Module and Arduino Uno

When we talk about wireless communication, we know Bluetooth is one method of a popular communication between devices. Today many smartphones have the integrated Bluetooth chip and have the capability to communicate using it. This is useful on many projects whose system requires a wireless communication protocol. The main issue here is to explain how to wire the Bluetooth module with Arduino and how to make it send and receive data to and from another device wirelessly. Figure 5 depicts the wiring of the Bluetooth module with Arduino.

The communication for data exchange between the Android device and Arduino starts after connectivity is established via the Bluetooth module. The Bluetooth module and Arduino microcontroller are connected in Fig. 3 and the Android app communicates with the connected devices in order to send and receive data. If the Android app sends the letter "T" or "H" or "E" to the Arduino, the Arduino will

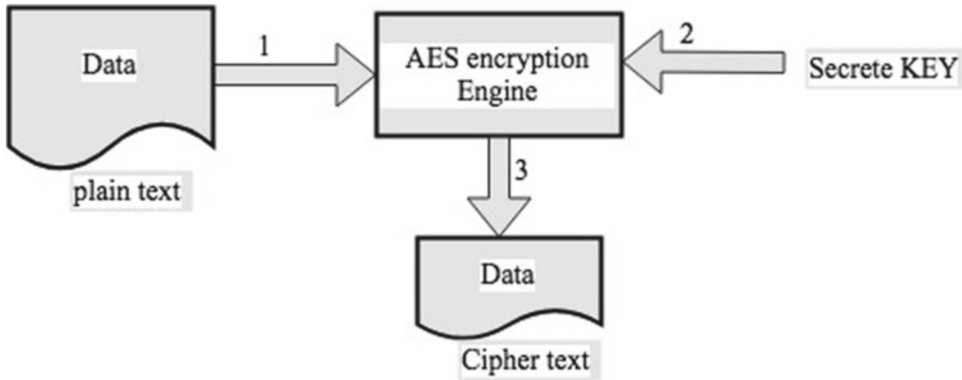


Fig. 3 AES encryption algorithm structure

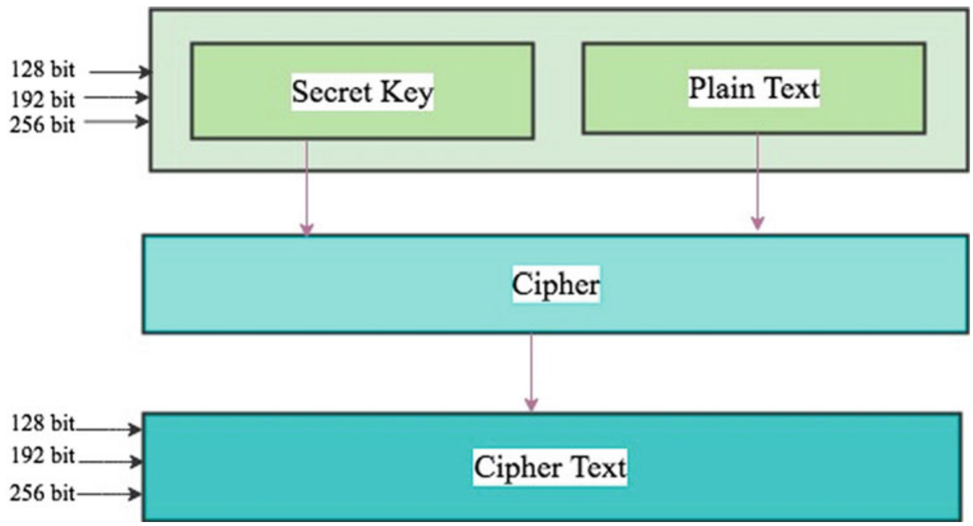


Fig. 4 AES algorithm diagram

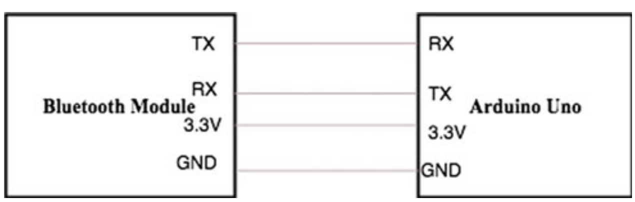


Fig. 5 Bluetooth and Arduino connectivity

send the data obtained from sensors via the outstream of the Bluetooth module.

4.6 The Working Flow of Bluetooth

The working flow of Bluetooth is illustrated in Fig. 6. In this section, several seamless functions are performed before the data is transmitted and received data via Bluetooth. Here, first ensure that an Android device supports Bluetooth and if it supports it, Bluetooth must be turned on. Then, the smartphone will be paired and connected with the Bluetooth module on the Arduino. Finally, the Android sends and receives data through the same shared channel RFCOMM protocol between both devices.

4.7 Smartphone Working Flow

In this system, a smartphone is used as BS. The working flow is showed in Fig. 6. A patient's data which will be send from a smartphone has four attributes: patient ID, patient name,

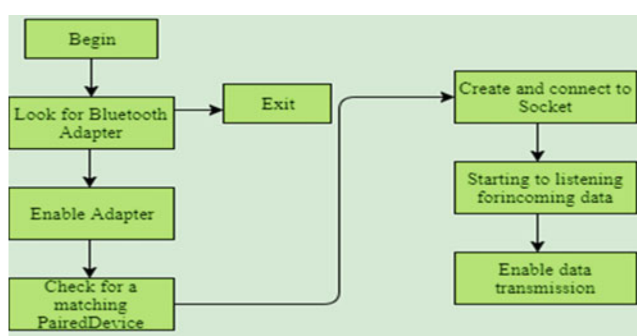


Fig. 6 Bluetooth working flow diagram

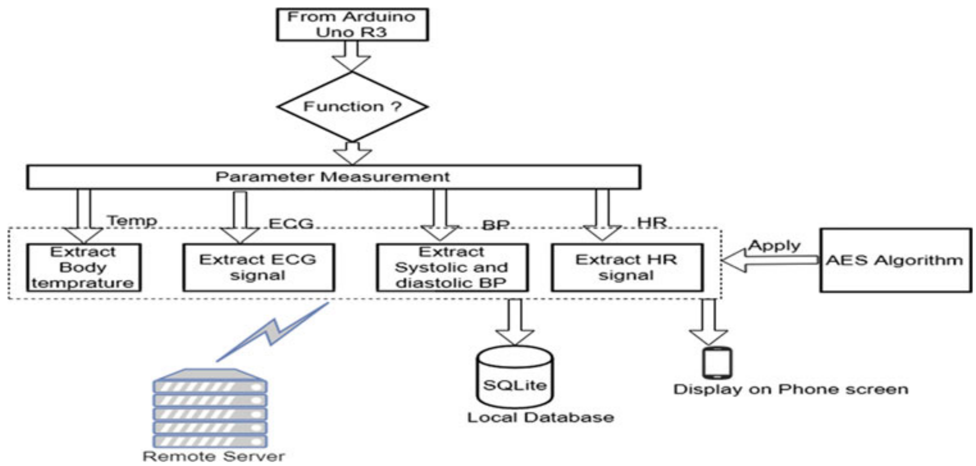


Fig. 7 Smartphone working flow diagram

Bluetooth ID and physiological data. After it receives physiological data it packets it to a third-party body-database server, a SQLite local server, doctors in the SMS message with all its fields. When global network is unavailable, patient data will be stored in the SQLite database. In order to make an alarm system, comparison functions of data will be processed in the smartphone, based on threshold value setting (Fig. 7).

4.8 Alarm Systems

The proposed system has the capability of issuing an alarm to notify health care personnel in cases of an emergency happening on patient vital signs. The alarm system is on threshold data values comparison (Sim et al., 2012; Goldberger et al., 2008) (Fig. 8; Table 1).

5 Simulations

The effectiveness of the system is measured after the simulation of the system is completed.

To achieve the result in order to take diagnoses, we have threshold value for normal and abnormal physiological sign values. This setting helps the smartphone to sound alerts to health care when the value is out of range. For individual patients, any collected data can be stored in his/her local storage-SQLite and removed from it. The packet which has a

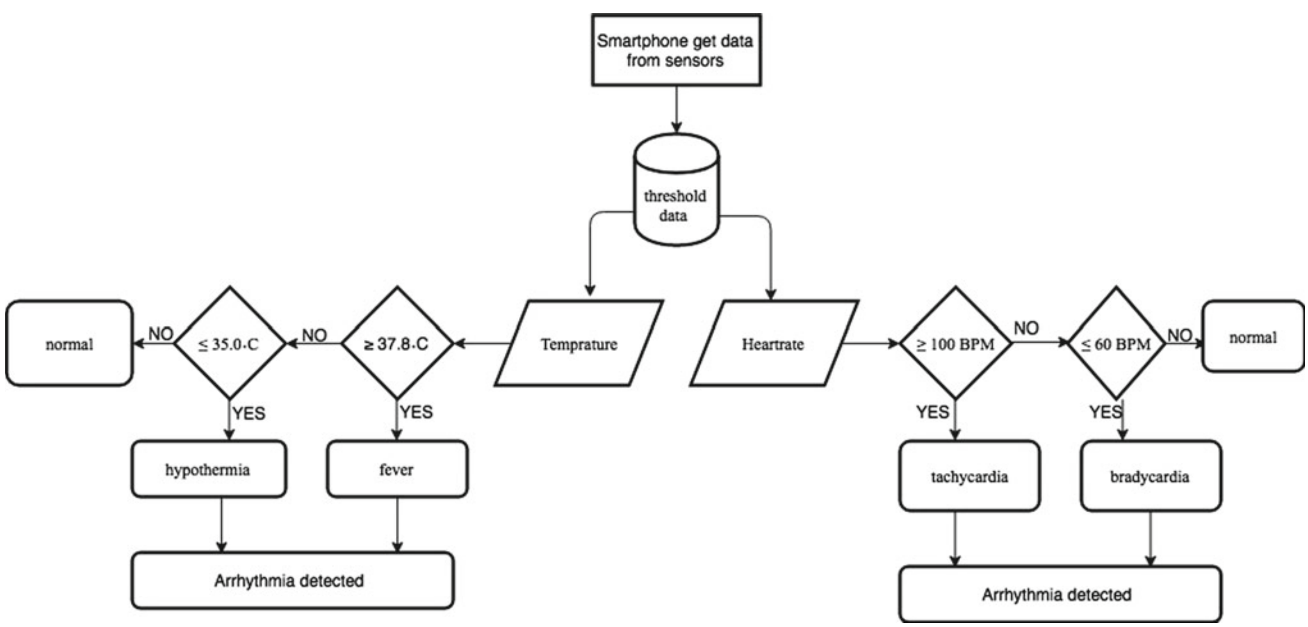


Fig. 8 Flow chart of alarm mechanism

Table 1 Threshold values of heartrate and body temperature, adult person, for alarm mechanism

Sinus rhythm type	Threshold value of body temperature	Threshold value of heart rate
Normal	36.5–37.5 °C	$60 \leq$ HR $\leq$ 100 BPM
Hypothermia	≤ 35.0 °C	
Fever	≥ 37.8 °C	
Pathological tachycardia		HR $\geq$ 100 BPM
Pathological bradycardia		HR $\leq$ 60 BPM

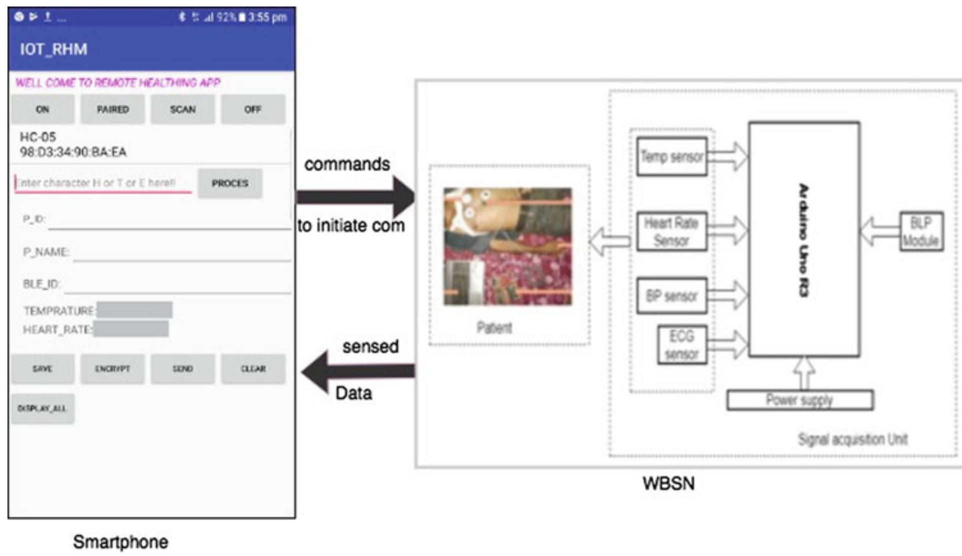


Fig. 9 The combination of a smartphone and body sensors

Fig. 10 Demonstration of IoT and smartphone-based remote health monitoring system Android application

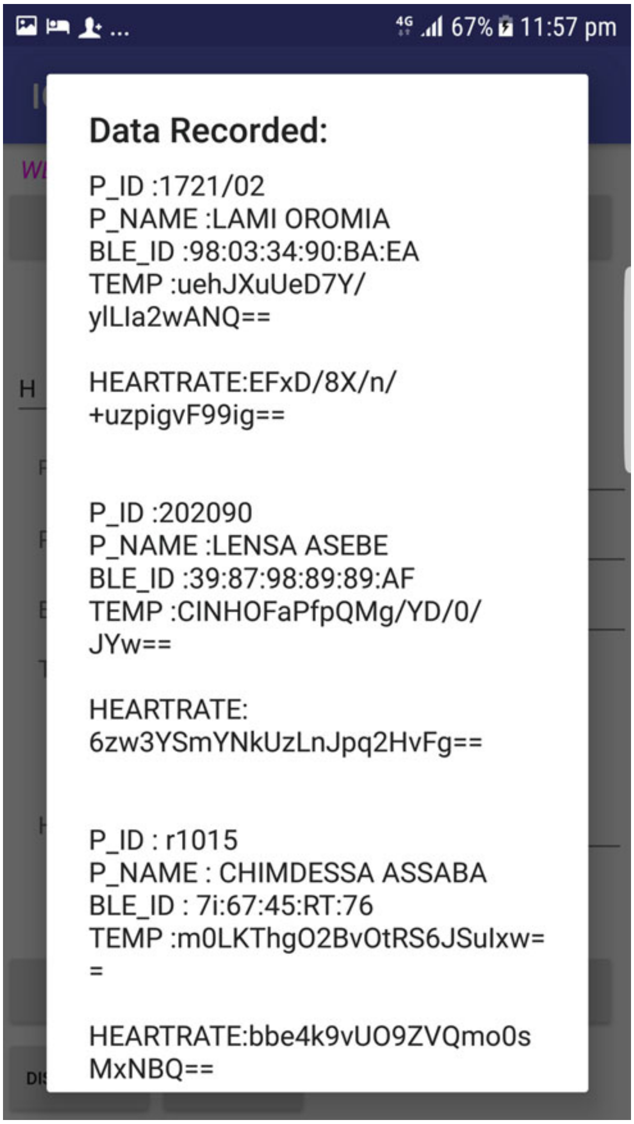


Fig. 11 SQLite local database recorded data screen on simulation device

permission to be sent via Wi-Fi to a remote server can be stored in the MYSQL server. This permission avoids the complexity and business of the server (Figs. 9 and 10).

Every patient can do the necessary tasks on the data obtained from the sensors and visited on their mobile phone. He/she can be sent, store, save, clear, secure and display their own information. They can be stored locally or remotely for every patient with their unique other information to identify them from other patients (Fig. 11; Table 2).

6 Results and Analysis

In this study, the IoT and smartphone-based remote health monitoring system is developed for monitoring cardiac parameters such as heart rate, temperature and ECG and are being obtained using worn sensors attached on the patient's body. The Android application has been developed to receive, store and transfer patient-related data to a remote server using wireless communication. From the remote server, a privilege is given for authorized doctors/family to know the medical status of a patient and deliver the treatments for patients.

The practical implementation of IoT and a smartphone-based remote health monitoring system is examined to determine the accuracy, ability, compatibility, usability and performance of the system by calculating the error rate of the patient's vital signs.

The practical implementation process of the system involves the participation of five patients with different ages. Before going to use the developed system, we have to record patients' vital signs by using certified medical health devices used in hospital as actual data; then each patient wears wearable sensors, and we are use the system to acquire medical information. With the approach presented in the paper (Islam et al., 2020) states that health related parameters are measured by the healthcare assistants which is a manual method that can be automated with our approach. Hence human load can be reduced. The error rate is less than 5% for all patient's medical information, this means the rate of success between the actual data and observed data is approximately greater than 95% for all cases of the developed remote health monitoring system (Tables 3 and 4).

Table 2 MYSQL database containing data recorded

patient_ID	patient_Name	BLE_ID	Temp_Value	HeartRate_Value
r1015	CHIMDESSA ASSABA	7i:67:45:RT:76	m0LKThgO2BvOtRS6JSulxw==	bbe4k9vUO9ZVQmo0sMxNBQ==
u8o65	KUMELA HORA	7i:f6:87:23:eu	z9eVvJmBUaUYvpDvnKHn0Q==	yRwUC6W9Ezmr6QR7okmiVw==
u8uk	KUMSAA MORODA	yi:k6:87:23:eu	lA4draHc0tl+buRNXH1DxQ==	RozuFgZ1ymbkX3SDjVlv2Q==
y789	JIMA HORA	7i:f6:87:23:ey	RE5ILWlmxuJPmxZFYCyepQ==	HRuOD+GdyfcxDvM0gewcgw==
202090	LENSA ASEBE	39:87:98:89:89:AF	ClNHOFaPfpQMg/YD/0/JYw==	6zw3YSmYNkUzLnJpq2HvFg==

Table 3 The statistical summarization of body temperature data obtained by a standardized machine used in hospital (actual data) and temperature sensor used in the system (observed data) in degree Celsius °C

Patients	Actual data (°C)	Observed data (°C)	Error data (%)
P_1	31	30	3.2
P_2	25	24	4
P_3	38.4	37.7	1.8
P_4	36.9	37.5	1.6
P_5	38.2	37	3.14

Table 4 The statistical summarization of pulse heart rate data obtained by a standardized machine used in hospital (actual data) and pulse heart rate sensor used in the system (observed data) in BPM

Patients	Actual data (BPM)	Observed data (BPM)	Error data (%)
P_1	67	68	1.49
P_2	73	72	1.36
P_3	70	73	4.28
P_4	80	83	3.75
P_5	75	73	2.66

7 Conclusions and Future Works

When people age their bodily strength dramatically decreases, but on the opposite side, health care costs, and queues for health in getting services are increasing. For these reasons, an urgent solution is needed with advanced technologies to handle the health services problems.

Here, we have developed the system which is potentially an essential in the medicine and health fields and which is more effective for both costs and services. The value of employing smartphones and wearable sensors is applied in this system. The IoT and smartphone-based health monitoring system integrates wearable sensors, smartphones, wireless body area networks and the storage system.

The future work of the system is with smaller and more effective sensors that can be embedded within soldiers' uniform cloths, to be used in the government military forces areas for monitoring soldiers' body hydration, heart beat and body temperature. The main problem in the developed system is a delay time. Because of the data stored in the Cloud the time required to process is long. So, for our future work we shall solve this problem by Fog technologies.

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