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IoT-Based Monitoring System for Diagnosing Adverse Drug Reactions and Enhancing Drug Compliance in TB Patients

Anshu SHARMA[1)*], Anurag SHARMA[2)], Rahul MALHOTRA[3)]

[1)] *School of Computer Science & Engineering, Lovely Professional University, Phagwawa, India*

[2)] *Faculty of Engineering Design and Automation, GNA University, Phagwara, India*

[3)] *Department of Electronics & Communication Engineering, CTIEMT, Jalandhar, India*

[*] *Corresponding Author e-mail: asharma406@gmail.com*

Health plays a prime role for day-to-day working. IoT provides physicians and patients with advanced medical resources, solutions, services, advantages etc. The goal behind the internet of things (IoT) is to have IoT devices that self-report in real-time. This project aims to develop a system that provides live-body temperature, cough detection, pulse rate and other health criteria such as weight loss, chest pain detection, blood sugar level, HB-WBC-RBC (hemoglobin, white blood cell, red blood cell) level, etc. NodeMcu, an open-source firmware, is used for wireless data transmission on an IoT platform. The data is stored on a web server so it can be accessed by both the physician and patient to provide the information about the patient's condition and help the physician to diagnose TB for the patient. The data of 50 patients have been collected for analysis and reviewed in detail in the result and analysis section.

Keywords: NodeMcu, MQ telemetry transport, tuberculosis, IoT: health care.

1. Introduction

The Internet of Things, also known as IoT, describes the billions of physical devices with sensors, processing ability, software and other technologies connecting and exchanging data with other devices/systems via the internet or other communication networks. These devices are used in daily life around the world and enable to share data, social content, etc. Because of the presence of unobtrusive chips and inclusive remote technologies, nowadays the IoT is reshaping and making the world around us increasingly responsive and convenient, therefore enhancing its progress [1, 2]. With the help of IoT, the data can be sent to the IoT cloud. IoT clouds are widely used for storage as data is stored in the database. Further, everyone can access this data whenever they need it. With the help of microcontrollers and sensors, data (log values) can be sent directly to the IoT cloud [3].

Nowadays, most devices are controlled with the help of the internet. An IoT ecosystem is made up of web-enabled smart objects that gather, communicate, and analyze data collected from various locations using embedded systems like processors, sensors, and computer networks. IoT devices transmit sensory data to the cloud for evaluation or localization by communicating to an IoT gateway or other external devices. For example, light bulbs can be turned on and off with the help of IoT. The same applies to the billions of physical devices present around the world, which must be connected to the internet and collect and share the data generated by various devices [4]. According to the reports, in 2050 there will be approximately 24.9 billion connecting devices of IoT available in the world [5]. When something is connected to the internet, it can send or receive information on a mobile phone or desktop, or both.

Wearable devices such as wristbands and other wireless devices such as blood pressure and heart sensors, etc., are connected to the IoT world and give patients access to their personal health information. These wearable devices can be used to remind about tests, show blood pressure variations and much more. With the help of these wearable and other home-based monitoring devices connected to IoT, physicians can effectively keep track of their patients' health. They can track patients' adherence to treatment plans and quickly detect any need for immediate medical attention. Such devices enable health care professionals to monitor and communicate with patients on an ongoing basis. Data collected from IoT devices can help physicians detect fever, monitor pulse rate and provide the best treatment for their patients and achieve the desired results.

In this paper, an IoT sensor is used for detecting fever, cough and pulse rate of patients in a real-time, while other conditions such as weight loss, chest pain, blood sugar level, HB-WBC-RBC level, etc., were taken from the selected offline data of 50 patients. All this is reviewed in detail in the results and analysis section. The username and password have been provided to patients so they can access their accounts and see their illness history readings such as weight loss, chest pain, blood sugar level, HB-WBC-RBC level, etc., by using the android application. This android application has been developed specifically for this project and is helpful for both patients and physicians. The physician can see the list of active patients and delete and update patients' readings such as weight loss, chest pain, blood sugar level, HB-WBC-RBC level, etc. These health readings can be accessed by patients by logging with their ID.

The major cause of tuberculosis (TB) is bacteria Mycobacterium tuberculosis, which most commonly cause pneumonia. Tuberculosis is both treatable and avoidable. It spreads quickly from individual to individual. When persons with pulmonary tuberculosis cough, sneeze, or spit, they spread TB bacteria into the air. Only a few of these germs inhaled by a person gets him infected with tuberculosis. When a person develops active TB (disease), the symptoms (cough, fever, night sweats, weight loss, etc.) may be mild for many months. This can lead to delays in seeking care, and results in transmission of the bacteria to others.

This research article is organized as follows. Section 1 presents the introduction and defines tuberculosis, and the literature overview is presented in Sec. 2. Section 3 presents the IoT device for monitoring, and interfacing of sensors is described in Sec. 4. Section 5 describes the results and analysis, and the conclusion and future scope are presented in Sec. 6.

2. Literature survey

IoT connects the actual world with the virtual world of the internet. The world comprises household items (such as thermostats, air cleaners, etc.), automobiles, industrial equipment, buildings, medical equipment, and the human body. Using IoT in health care will help improving human health, aid in standard control/monitoring of chronic diseases, and provide risk alert and life-saving interventions. Since 2003, experts from around the world have been conducting research in the field of intelligent IoT-based human health research [23]. As a result, some experts have developed smart wearable shirts/dresses to help in solving people's health problems. Li *et al.* [6] developed a simple smart wearables acceptance model for older adults, and identified factors that contribute to the use of smart wearable technology, including a human's health condition status report. Akbulut and Akan [7] developed a smart wearable design system that monitors patient's heart disease, providing continual medical monitoring to patients. Akhila *et al.* [8] monitored older persons' health in real-time while they were in nursing homes or hospital by checking the air quality in the room, pulse rate, temperature, and electrocardiogram. Kumar *et al.* [9] classified and audited the advancement on coughing sound investigation with an advanced AI model and gathered a database of 112 patients to test the viability of their model. Hataji *et al.* [10] showed that smart watch-based monitoring in combination with tiotropium and olodaterol may improve daily physical activity in chronic obstructive pulmonary disease patients. Petrović and Kocić [11] explored how cost-effective IoT devices such as cough detection, air quality control and contact tracing can reduce the spread of coronavirus in indoor areas. Grym *et al.* [12] pointed out that smart wristbands are an effective monitoring tool of health parameters during pregnancy.

A smart home is also the main IoT technology program in the field of intelligent human health services. Tripathy *et al.* [13] developed a smart COVID-shield that can automatically detect prevailing symptoms such as fever and coughing and ensure that social distancing rules are properly followed. Pham *et al.* [14] developed a cloud-based environmentally friendly (CoSHE) proposal for home healthcare. Farhana *et al.* [15] developed a smart home system that can quickly determine natural phenomena and health risks for patients. Chakraborty and Jeberson [26] provided reinforcement learning for medical information processing over heterogeneous networks.

3. IoT devices for monitoring

The sensors used for monitoring were: NodeMcu (controller), body temperature, cough sensor and pulse rate sensor.

3.1. NodeMcu

NodeMcu is a low-power system with microcontroller with integrated Wi-Fi on a chip. It is intended for cell phones, connecting to Wi-Fi, wearable instruments and other types of IoT applications and platforms. NodeMcu fulfills ultra-low force utilization with a mix of a few kinds of restrictive programming, for example, fine-grained clock gating, different force modes and dynamic force scaling. It can work well in mechanical conditions, with a working temperature in the range from $-40°C$ to $+125°C$. Among many other functions, it uses cutting edge alignment hardware that allows connecting to any Wi-Fi network in a given area.

One needs to determine the global variables and credentials of the Wi-Fi network, the first is the name (SSID) and the password [16]. To use Arduino to program the NodeMcu, one needs to introduce it to the software first. After writing the full code in Arduino, the code is compiled and run to the NodeMcu. It provides very easy functionality of connecting to the internet and a Wi-Fi network as per availability, providing a local IP at the same time. Internet connection and power supply of 5 V are required to transmit data to the server.

3.2. DHT11

DHT11 uses a capacitive humidity sensor and a thermistor to calculate the incorporating air, and sends an electronic signal on the data pin (no straightforward information pins required). It is really easy and simple to use and it is lightweight, yet it requires mindful intending to get data in every minute. It has three pins: the first pin is for VCC, the second pin is for GND, and the third pin is D0 [21]. These three pins are connected with 0.1 spacing. each with the body size of $15.5 \times 12 \times 5.5$ mm. This sensor can operate under 5 V and also be used with the Arduino [17]. It will stick to the human hand to record body temperature.

3.3. Cough sensor

The grove – the gas sensor (MQ2) module is used for cough detection, ready to detect H2, LPG, CH4, CO, alcohol, smoke, and propane levels. Due to its high sensitivity and fast response time, measurements can be taken very quickly. The sensitivity of this sensor can be controlled with a potentiometer. This sensor has a stable and long-life span. It has four pins. PIN 1 can be used for voltage (+5), PIN 2 can be used on the ground, while the other two PINs are analog and digital, and they are defined as A0 and D0, respectively. This sensor will detect the sound of coughing when the patients cough.

3.4. Pulse rate sensor

The pulse rate sensor measures pulse waves, which are changes in the volume of a blood vessel that occur when the heart pumps blood, and they are detected measuring the change in volume using a pulse rate sensor. The patient will have to put his/her finger on the sensor to record pulse rate.

4. Interfacing of sensors

4.1. Interfacing of DHT11 with NodeMcu

The first step is to transmit body temperature to IoT cloud. DHT11 has three pins: voltage, ground and data. The D15 data pin is used as an output pin for temperature. With the help of DHT11, the human body temperature can be monitored. This DHT11 easily attaches to the human body and records the human temperature. The voltage pin is directly connected to the NodeMcu voltage, while the ground pin is connected to the ground node, as shown in Fig. 1.

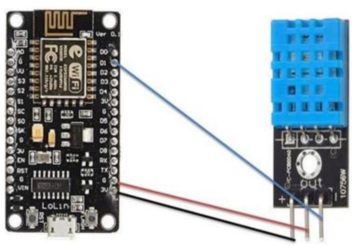

Fig. 1. Interfacing of NodeMcu with DHT11.

4.2. Interfacing of NodeMcu with MQ2 and pulse rate sensor

The ground pin of MQ2 is connected to the ground pin of NodeMcu. The voltage (V0) pin of MQ2 is connected to the 3 V of the NodeMcu, and the output pin (A0) of MQ2 is connected with the digital pin (D2) of the NodeMcu, as shown in Fig. 2.

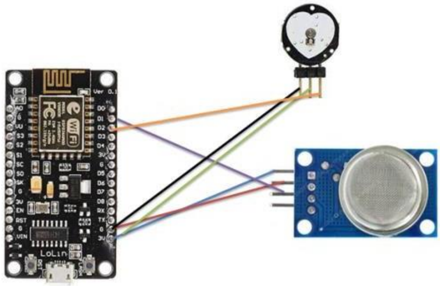

FIG. 2. Interfacing of NodeMcu with the cough (MQ2) and pulse rate sensors.

4.3. Implementation of the IoT-based monitoring system

Cough sensor includes the following modules to transmit data on cloud:

a) sensor module,
b) controller module,
c) power module.

4.3.1. Sensor module. Sensor modules, e.g., the gas sensor and the temperature sensor, are very important devices that detect and respond to some type of input from the physical environment. Temperature module is lightweight, easy to handle and known as a thermistor. The sensor comprises of two devices that generate electrical voltage or resistance when detecting temperature changes. The temperature sensor plays a key role in maintaining a certain temperature inside any substance. It consists of a capacitive humidity sensing element and a thermistor for sensing temperature. On the other hand, there is a cough sensor that detects a change in air quality with a small potentiometer, which allows the adjustment of the load resistance of the sensor circuit. With the help of these modules, the log values can be transmitted directly to the IoT cloud. These sensors can also detect a weak signal with the help of a power module. This sensor can operate on 3.3 V.

4.3.2. Controller module. In the case of monitoring, NodeMcu has been used to control sensors. NodeMcu is a Wi-Fi module used to transmit the information or data on a server.

4.3.3. Power module. Power module is generally used to provide energy to the controller and sensor.

4.4. Message queuing telemetry transport

A message queuing telemetry transport (MQTT) is a network protocol. It is a lightweight publish-subscribe device [18]. MQTT is a simple messaging protocol used when bandwidth of the network is low. It is also responsible for sending commands to the server to control outputs and also reads published data from the sensor nodes [19].

MQTT consists of the four concepts: publish/subscribe, messages, topic and broker. The first concept of MQTT is to publish and subscribe model that removes direct communication between the message publisher and the recipient/subscriber. The broker's filtering activity makes it possible to control which client/subscriber receives which message. The second concept: message, contains information that one wants to exchange between the device and the server. The topics are very important part of the MQTT, as the receiving clients subscribe to the broker for topics of interest and the broker ensures that the receiving client gets all message published to the subscribed topics. Topics are always described as strings separated by the forward slash. The broker in MQTT receives and filters the message. The broker can also publish the message to the subscribing clients. There are many brokers that can be used, but for home automation, a mosquito broker is used that can be installed with the help of Raspberry Pi. Alternatively, a cloud MQTT broker can be used.

List of parameters detected with their descriptions are presented in Table 1.

The system presented in this study consists of mobile apps.

4.5. Doctor App

Doctor App (can be used by doctor as well as patient) is a mobile app that consists of information about the patient. A unique identification number (UIN/IC) will be provided to the patient for login. The patient can respond to the doctor and monitor his/her disease history through this mobile app.

A patient can see his real-time monitoring. If the patient coughs, the log values will be detected and the doctor will receive a notification. The temperature of the patient will be updated every 1 hour automatically (Fig. 3).

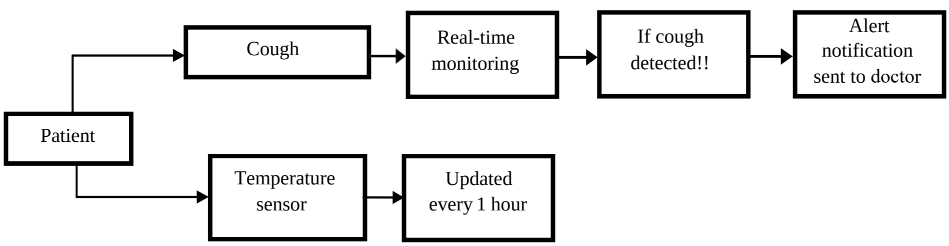

FIG. 3. Methodology of system.

Table 1. List of parameters.

No.	Parameter	Description
1	Cough	Coughing is a reflex action that clears one's throat of mucus or other irritants. When something irritates the throat, the nerves send a message to your brain. The brain then tells the muscles in your chest and abdomen to expel air from your lungs to release mucus or irritants [21].
2	Chest pain	Chest pain or discomfort due to heart disease [22].
3	Hemoptysis	Hemoptysis is a condition when a person coughs up blood or blood-stained mucus from his/her lungs or bronchial tubes. It can be a sign of a critical health condition. Bacteria, cancer, and vascular problems in your lungs can cause this condition [23].
4	Fever	A fever is a temporary increase in body temperature and usually occurs due to illness [20].
5	Fatigue	Fatigue is a term used to describe a complete feeling of tiredness or lack of energy. It is not the same as feeling drowsy.
6	Weight Loss	Weight loss, in the context of medicine, health, or physical fitness, refers to a decrease in the total body mass, due to a loss of fluid, body fat (adipose tissue), or lean mass (i.e., mineral bone deposits, muscle, tendon, and other connective tissue).
7	Night sweet	Night sweats are repeated episodes of heavy sweating during sleep.
8	Hemoglobin level	Hemoglobin, abbreviated HB or HGB, is an oxygen-carrying metalloprotein that contains iron in the red blood cells of almost all vertebrates and the tissue of some invertebrates. Hemoglobin in blood carries oxygen from the lungs or gills to the rest of the body [24].
9	Red blood cells level	Red blood cells (RBC) carries fresh oxygen throughout the human body. Hemoglobin is the protein that resides inside the RBC.
10	White blood cells level	White blood cells (WBC) act as a protection layer that helps the human body to fight infection and other diseases.
11	Blood sugar	Blood sugar, or glucose, is the main sugar found in human blood. It comes from the food one eats, and is a major source of energy for one's body. The blood carries glucose to all the cells in the body to be an energy source [25].
12	Skin Test	Skin tests can be performed to detect rashes on human skin, acne, allergies and food allergies, bacterial or fungal infections of the skin, and other diseases.

Here are the steps for the patient while using this app.

Step 1: Open the doctor app. Two options have been provided for the patient: "Go to Login" and "Put your Detail" sections.

Step 2: In the "Go to Login" section a new window will open, and the patient can log into his/her account with an ID number and password.

Step 3: After the login, a new window on the screen will open for the patient. The patient can see his/her basic information and send a message to the doctor whenever needed. The patient can also update his/her data and easily log out of his/her account.

Step 4: The patient can also fill in his/her disease information by clicking the "Put your Detail" section, as shown in Fig. 4.

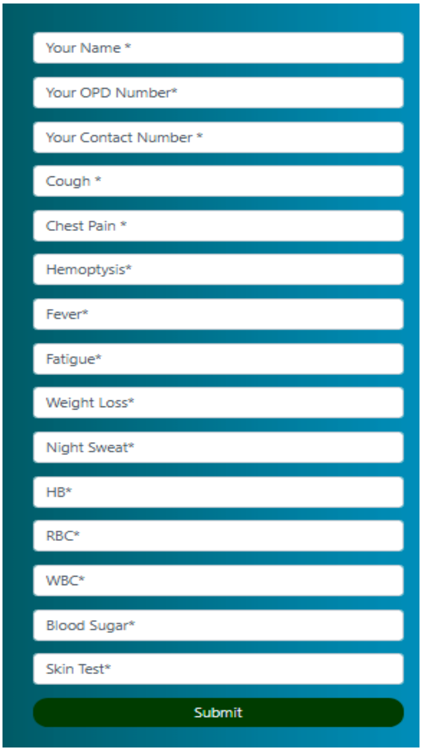

Fig. 4. Patient graphical user interface (GUI) for filling illness information.

Here are the steps for the doctor for using this app.

Step 1: In the first step, the doctor will log into his/her account by using his/her ID and password.

Step 2: After the login, the doctor can see the list of active patients and reply to patients' queries. The doctor can update and delete the patients' info at any time, as shown in Fig. 5.

Step 3: The doctor can view the patient disease history by clicking on the patient history section.

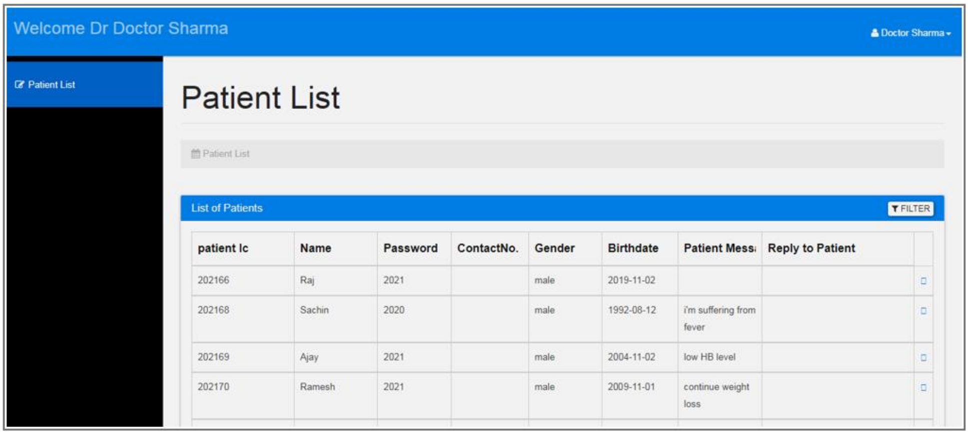

FIG. 5. List of active patients for the doctor.

5. Results and analysis

Google Sheet has been used for the database of the system. Data from Google Sheet can be easily exported to Microsoft Excel for analysis. Google Sheet offers different types of charts for data, such as line charts, column charts, pie charts, bar charts, scatter plots, and others as needed. For the result and analysis, the data of 50 patients have been collected and used.

When it comes to coughing, 32% of patients have mild condition, 60% of patients have moderate coughing and 8% of patients have extreme coughing, as shown in Table 2. At least 8% of people may have a chance of first symptoms of active tuberculosis (TB). It usually starts as a dry irritating cough. It tends to continue for months and gets inadequate attention. Patients with a high chance of TB should cover their mouth when sneezing or coughing, wash their hands after coughing or sneezing, keep all doctor appointments, communicate with the doctor via the android app and take the medications as suggested by the doctor.

TABLE 2. Reports of cough, chest pains, hemoptysis, fever, fatigue, weight loss and blood sugar levels.

Patient condition	Symptoms						
	Cough	Chest pain	Hemoptysis	Fever	Fatigue	Weight loss	Blood sugar
Mild	32	82	58	16	78	38	62
Moderate	60	18	24	52	12	44	26
Extreme	8	0	18	32	10	18	12

82% of patients have mild chest pain, while 18% of patients have moderate chest pain, as shown in Table 2. 58% of patients have mild hemoptysis, 24% of patients have moderate, while 18% of patients have extreme hemoptysis, as shown in Table 2. According to studies, about 8% of patients with pulmonary tuberculosis (PTB) will develop hemoptysis at some point in their lives. In 90% of extreme hemoptysis cases with severe hemoptysis, bleeding may occur due to high bronchial blood pressure. The etiology of hemoptysis in a post-primary TB patient is diverse. Next, we consider patients with fever. 16% of patients have mild fever, 52% have moderate fever, while 32% have high fever. In the live monitoring, when the body temperature goes above 37°C, the alert notification will be sent to the doctor via the NodeMcu. The doctor can suggest medications for the patient and communicate by using the "Doctor App". 78% of patients have mild fatigue, 12% have moderate, while 10% of patients have extreme fatigue. Patients with extreme fatigue problem can communicate with the doctor through the mobile app. 38% of patients have mild weight loss, 44% have moderate, while 18% have extreme weight loss, as shown in Table 2. In addition to causing symptoms such as coughing, fatigue and fever, TB often results in significant weight loss and lack of appetite. At least 18% of patients with extreme weight loss may have a high chance of developing TB. 62% of patients have mild blood sugar level, 26% of have moderate, while 12% have extreme blood sugar level. At least 12% of patients with extreme glucose level are at risk of developing diabetes. Sometime with untreated latent TB infection and diabetes is more likely to develop TB.

32% of patients have less HB level, while 62% have normal HB level, as shown in Table 3. Anemia can be defined as hemoglobin (HB) levels below 12.5 g/dL for women and 13.5 g/dL for men. A number of low HB patients may develop iron deficiency and chronic inflammation. 32% of patients have less RBC levels, while 62% have normal RBC levels. Patients with low RBC levels may develop a chronic disease. 32% of patients have less WBC level, while 62% have normal WBC level. Patients with low WBC levels may develop chronic disease.

Table 3. Blood levels.

Levels	Hemoglobin (HB)	Red blood cells (RBC)	White blood cells (WBC)
Less	32	32	32
Normal	62	62	62

78% of patients have negative skin test report whereas 22% of patients have positive skin test report. Patients with positive skin test report may develop chronic disease.

The combined data of nine patients have been taken for live temperature monitoring for 12 hours (9:00 AM to 9:00 PM), as shown in Fig. 6. When body temperature goes above 37.2°C, the patient suffers from fever. As shown in Fig. 7, four out of nine patients have been suffering from fever. This data has been collected from Google Sheets.

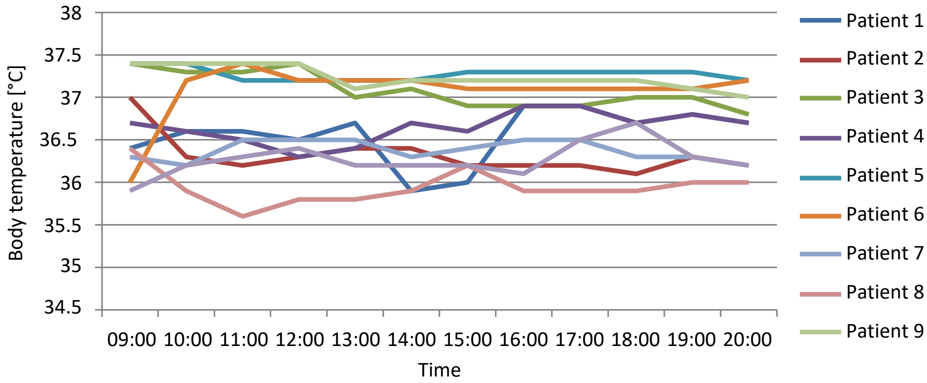

Fig. 6. Fever report of nine patients.

Fig. 7. SMS notification from the patient received by the doctor.

If the patient coughs, coughing notification is sent to the doctor's mobile. The doctor can communicate and suggest medications via the "Doctor App". As shown in Fig. 7, the doctor received a mobile SMS.

A patient places a hand finger on the sensor device to record the pulse rate. When the patient keeps his finger on the pulse rate sensor, the sensor records the log values and sends the log values to the IoT server. On the server, the threshold has been set for the pulse rate when it goes above 120 BPM. Figure 8 shows the live monitoring of the patient's pulse rate.

Fig. 8. Live monitoring of the patient's pulse rate.

If the patient's pulse rate becomes abnormal, the notification is sent to the doctor's mobile. The doctor can respond and suggest medications via the "Doctor App". Figure 9 shows the SMS notification of the patient's abnormal pulse rate received by the doctor.

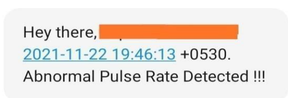

Fig. 9. SMS notification of the patient's abnormal pulse rate received by the doctor.

6. Conclusion and future scope

This research considered the IoT-based healthcare system. Nowadays, it is necessary to create a cost-effective, user-friendly and self-monitoring platform for a smart healthcare system. It provides the people with efficient and effective solutions to stay at their homes instead of going to hospitals. The android app has been developed in which the doctor and patient can communicate with each other. A user-friendly GUI has been designed for the patient in which the patient can see his/her illness history by logging with their username and password provided by the doctor. The data of 50 patients have been selected for the analysis, and the data of 10 patients have been used for the detection of fever. Patients with extreme coughing, weight loss, fever, blood sugar, fatigue and chest pain may have a high chance of developing TB. By using a "Doctor App", patients can communicate with the doctor at any time. The doctor can respond, provide instructions for medications and also be notified via SMS about the patients' coughing and high pulse rates.

The present study focused on various parameters considered for live body temperature, cough detection, pulse rate and other health parameters such as weight loss, chest pain, blood sugar level, HB-WBC-RBC level, etc. Future research work can be done in the following areas:

1. The sensor of blood glucose level will be added to record the sugar level of a patient in real-time.
2. More data of patients will be collected for analysis.
3. With the help of IoT, a patient will be notified via mobile SMS about his/her health condition such as fever report, abnormal pulse rate, regular pulse rate, etc.

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