AllY: Early Warning System for Asthma Patients based on IoT and AI

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Abstract. Today we all live in a digital era, where there are enough technologies especially based on the internet. Internet of things (IoT) is playing a vital role in the modern digital era, which connects most of the things using currently existing cutting edge networks and internet based technologies. The objective of this paper is to demonstrate a proposed IoT based early warning system for asthma patients. Many of such victims of this and similar diseases should have a very good quality the of air to breath. The air quality depends on various factors like smoke, dust, humidity, oxygen, carbon dioxide, and carbon monoxide, etc. concentrations. The proposed system has been developed based on Raspberry-Pi computer and related sensors to measure the air quality. The system uses some message handling protocols like IBM's Message Queuing Telemetry Transport Server to handle message transfers and some actuators like SIM900A GSM Module, etc. to alert the patients and other respective parties. Once the values of the said factors, that makes the air-quality, going beyond a pre-identified threshold values, the system is supposed to alert the patients and the corresponding parties to take emergency precautions. Further the IBM Watson IoT platform with some AI techniques like deep learning models are also being used to make certain predictions against some input factors like, patient's heart rate, blood pressure etc.

Keywords: Asthma Patients, Raspberry-Pi computer, Internet of Things, MQTT Protocol, Node-RED

1 Introduction

According to the statistics published by the World Health Organization (WHO), there would be nearly three hundred million population among the world's population who have been suffering from Asthma. It is estimated that this figure would be increased by up to four-hundred million by 2025. In Sri Lanka, even though it is not a crucial figure, in India, there are nearly 11% of people are suffering from chronic lung diseases like asthma [1]. The most vulnerable groups of people for these types of lung diseases are adults, infants, toddlers, and pregnant women. The main cause of the problem is the polluted air. Particularly in some Intensive Care Units (ICUs) of hospitals also as there is no proper ventilation, patients may suffer from breathing problems that are at risk. Especially elderly people suffered a lot and with the lack of immediate help they may be undergone in critical conditions. In some of the hospitals, evenly in Sri Lanka, the patient and nurse ratio is also comparatively low. All the patients are not monitored on time. With the help of technology, monitoring of the patient's conditions could be done without much difficulty without the help of the nurses.

Asthma is characterized as a typical, endless respiratory condition that causes trouble in breathing because of aggravation of the aviation routes. Asthma manifestations incorporate dry hack, wheezing, chest snugness and shortness of breath. Dr. Meyer [2] says that there is a noteworthy association between natural sensitivities and asthma. Hypersensitive responses and contamination would all be able to trigger an asthma assault. "Those with steady asthma frequently see a superior personal satisfaction with the assistance of calming solution," Dr. Meyer says. "Everybody who has asthma needs a protect inhaler to open aviation routes rapidly". As a rule, asthma begins in youth years and advances into adulthood. Be that as it may, be a few people in their 60's 80's can get grown-up beginning asthma. Dr. Meyer [2] says asthma is a reversible obstructive lung infection. He's seen asthma patients who can enhance their breathing stream rates superior to anything the individuals who have the respiratory infection known as COPD.

There is a way in implanted and organizing advancements, another developing Internet of Things innovation [1] is helpful for checking the patient's respiratory conditions with no outside help with the utilization of smoke and humidity sensors, the condition of the patients surrounding air is detected. Afterwards the data is fed in to the system for processing. In such a way IoT sensor gadgets create tremendous measure of information. The intention of this paper is to introduce a system which, monitor the air condition and immediately inform the relevant parties with the use of IoT based technologies.

The rest of the paper is composed in such a way that in the Section – II, it discusses about some similar work done. Section - III gives a detailed explanation about our proposed model and its functionalities. Outcomes acquired from the proposed work as the conclusion and some possible further work will be discussed in the Section - IV.

2 Related Work

Air-quality is the most significant factor to be monitored, in places where some patients with respiratory system related diseases like asthma patients are living in. Recent technologies have paved enough avenues for designing and developing effective and accurate techniques in measuring the air quality of an identified environment. Not only detection, providing the updated information about the air quality to the relevant authorities also a significant requirement. The recently developed technologies based on the Internet of Things (IoT) makes enough avenues in not only detecting but also transferring the air quality measurements to the relevant authorities in places like hospitals, where some patients with respiratory system related diseases are treated on. Due to the high significance factor of this need, there are quite enough work have been found in the related literature.

Somansh Kumar et al [3] have presented an approach for Air Quality Monitoring System Based on IoT with Raspberry-Pi. They have presented a real time standalone air quality monitoring system, which includes certain parameters like PM 2.5, carbon monoxide, carbon dioxide, humidity, temperature and air pressure. According to the authors the system has been tested in Delhi urban area and the measurements have been compared with the data provided by the local environment control authority and presented in a tabular form. According to the paper it has been said that the values also shown in the IBM Bluemix Cloud.

Raji, A et al. [4] have made a proposal on Respiratory Monitoring System for Asthma Patients based on IoT. According to the authors the respiratory rate was calculated using LM35 temperature sensor and monitored the patient's respiration continuously based on voltage value of inhaled and exhaled air. Using the NRF24101 sensor, data was transmitted to the Medical center from the home. Thereafter the data was published on a web server using Ethernet to inform the patient’s status to the doctor in taking necessary actions. Once it is reached the threshold, an alarm is operated and a message is generated in the web page. Therefore the Doctor could know the patient’s condition without much of the delay and could initiate necessary treatments immediately.

Marinov et al. [5] have proposed a method to monitor the environmental parameters with amperometric sensors and gas sensors with the use of PIC18F87K22 microcontroller. To monitor the environment in the real time sensor nodes were set-up in different areas. The results were displayed on the city map.

Jha, Mukesh et al. [6] proposed a system to monitor the environmental parameters modeling and manipulating micro climate of urban areas. The aim of implementing this system is to the adoption of efficient urban infrastructure by analyzing the urban microclimate.

A comprehensive study has been done on smart sensors, devices, objects and things in IoT by Xing Liu et al. [7]. Authors have also given various definitions for concepts of IoT in many ways. Some similarities and differences between the smart objects, smart things in IoT were also prescribed in a tabular form.

3. Proposed System

The main components of the proposed system can be classified as below. The system components could be identified as main hardware units, sensors, actuators, other hardware peripherals and software requirements of the system.

3.1 Main Hardware Units of the System

i. Raspberry Pi 3 B as the main hardware unit of the system

Raspberry-Pi (Fig. 1) is an ARM based credit card sized Single Board Computer (SBC) which invented by Raspberry-Pi Foundation [8]. A Quad Core 1.2GHz Broadcom BCM2837 64bit CPU and 1GB RAM included on board to make it capable of handling more complex tasks comfortably. This improved its performance up to ten times comparing with Raspberry Pi 1 and approximately 80% faster than the Raspberry Pi 2 in parallelized tasks according to the Benchmarks [9]. It comes with BCM43438 wireless LAN and Bluetooth Low Energy (BLE) on board as a new addition to the new model B 3 facilitating Wi-Fi functionality on it. Raspberry Pi has 40-pin extended GPIO, 4 USB 2 ports, 4 pole stereo output and composite video port, full size HDMI port, CSI camera port for connecting a Raspberry Pi camera, DSI display port for connecting a Raspberry Pi touchscreen display and Micro SD port for loading your operating system and storing data [3] [10]. Other than the Raspbian OS, a Debian-based Linux distribution which provides by the Raspberry Pi foundation operates on various Linux/Non Linux based operating systems could be used as the OS for Raspberry Pi. Raspbian OS was used to develop our solution.

Fig. 1. Raspberry Pi 3 Model B Unit

ii. Sensors of the System

We used three sensors to measure the concentration of several gas types and humidity level in the air with temperature. As MQ series gas sensors are known for accurate detection, we selected MQ2 (Fig. 2) and MQ135 (Fig. 3) sensors to measure the air quality and DHT11 sensor (Fig. 4) to measure the humidity and temperature values. These sensors can either be bought as simply the sensor or as a complete module. Commonly the MQ2 sensor is used to detect in house gas leakages. At the same time it can also be used to measure some other gasses like alcohol, propane, hydrogen, CO and even methane. There is a Digital pin which comes only with the module variant of the sensor adds ability to this sensor to work even without microcontroller. So it is useful on occasions which you only want to detect one particular gas. The analog pin of the sensor can be used to read the ppm values of each gas variant separately with the use of microcontroller [11].

Fig. 2. MQ2 Air Quality Sensor Module

MQ135 sensor can detect or measure common air quality gases such as CO2, NH_3, NO_2, Smoke, Benzene, and Alcohol [12]. It also has the same options similar to MQ2 which can be used to measure single type of gas using the digital pin or calculate ppm by reading analog values (0-5V) using a microcontroller.

Fig. 3. MQ135 Air Quality Sensor Module

DHT11 sensor is used to measure the humidity and temperature levels in the air. Normally it is used for garden and farm monitoring systems. The sensor consists of a capacitive humidity sensor and a thermistor to measure air condition. It returns the measurement converted into analog value by a chip integrated into the sensor [13]. The technology behind the sensor leads to high reliability and stability.

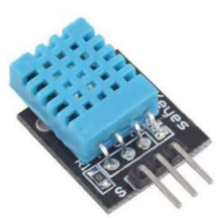

Fig. 4. DHT11 Humidity Sensor Module

iii. Actuators of the System

The two main actuators used in the system are SIM900A GSM Module (Fig. 5) and a Buzzer module (Fig. 6). SIM900A GSM Module [14] has Dual Band GSM/GPRS based SIM900A modem developed by SIMCOM. Working frequencies are 900/1800 MHz. It has the ability to search the two bands automatically and also can be set by AT commands. AT commands can be used to configure the baud rate from 1200-115200. It's an advanced module having TCP/IP stack inside providing an option to connect with the Internet via GPRS. Buzzer is a simple electronic product that emits sound that can be used for generating some sound / alarm. We can implement melodies on buzzers when connected it to GPIO pin.

Fig. 5. SIM900A GSM Module

Fig. 6. Buzzer Module

3.2 Other hardware peripherals for the System

i. MCP3208 Analog to Digital Converter

The sensor is a 12-bit 8 channel converter. The MCP3208 (Fig. 7) features a successive approximation register (SAR) architecture and an industry-standard SPI serial interface, allowing 12-bit ADC capability to be added to any PIC micro microcontroller [15]. It features 100k samples/second, low power consumption. The sensor is available as SOIC and 16-pin PDIP packages. We can use the sensor for applications like industrial PCs, motor control, industrial automation and data acquisition.

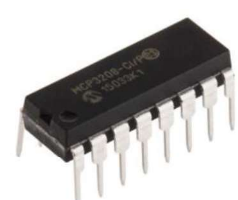

Fig. 7. MCP3208 Analog to Digital Converter

ii. Bi-Directional Logic Level Converter (4 Channel)

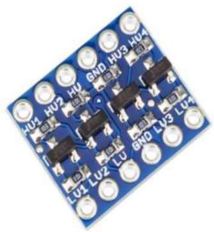

Fig. 8. Bi-Directional Logic Level Converter

Bi-Directional Logic Level Converter (Fig. 8) is a small device that converts 5V signals to 3.3V and vice-versa. It is a 4 channel converter so this can cope with 4 signals simultaneously and this also works with 2.8V and 1.8V devices [16]. To make the board to work it needs to power up by giving the two voltage levels. So the "HV" pin needs to be given the high voltage and low voltage to the "LV" pin. "GND" pin needs to be grounded as well.

3.3 Software Requirements for the System

A Simplified diagram which depicts the basic architecture of the proposed system is shown in Fig. 9.

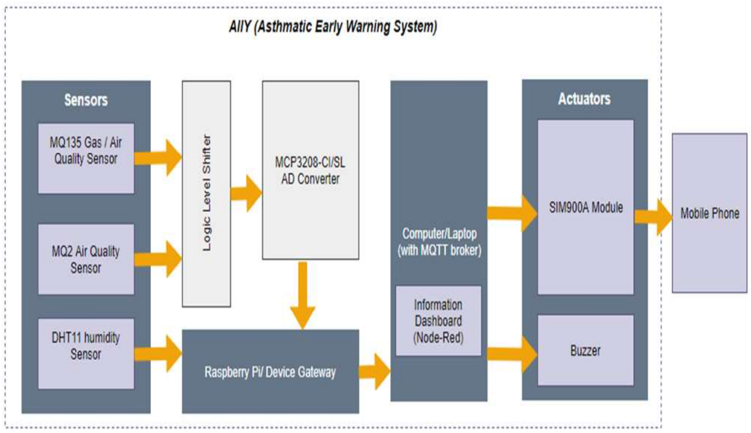

Fig. 9. Detailed Architecture of the System

The major controlling unit of our system is the Raspberry-Pi 3.0 B unit. Initially it had been expected to use two sensors and two actuators in our system. But later one more sensor was added to the system. I.e. MQ135 Sensor. MQ2 air Quality Sensor was used to detect Carbon Dioxide, Carbon Monoxide and LPG levels of the air and the DHT11 humidity Sensor was used to sense the humidity level of the air. The three sensors were connected to the Raspberry-Pi and as the MQ2 air quality sensor generates analog signals, we had to use MCP3208 Module to convert the analog signals generated by MQ2 Module to digital signals and send to Raspberry – Pi unit. A Buzzer and a SIM900A GSM Module were used as actuators of the system.
First the Raspbian Linux Based Operating System was installed in the Raspberry-Pi unit. Connecting the three sensors and actuators was done afterwards. Then an instance of MQTT Server was installed to the Laptop Computer, which would be acting as a main processing unit of the system. Installation of Node-Red GUI to the Laptop computer was also done afterwards.

Using the Analog signals, we checked the LPG, CO and smoke levels of the air and experimented by changing the threshold values of the respective sensors. Then buzzer generated some alarms depending on the above threshold values. Then the DHT11 humidity sensor was connected to the Raspberry-Pi unit and by changing its threshold values we let the Buzzer to operate. The SIM900A GSM Module was configured in such a way that it sends an SMS, once the Buzzer is operated. All the sensor data were transmitted through MQTT Server to the Laptop Computer, where the main processing was taking place. All the threshold values and limits were checked using the laptop computer as it needs a high processing power.

After processing the data in the laptop computer, the decisions regarding the sensor inputs were sent through MQTT Server to the Raspberry–Pi unit to activate the actuators in the system. Then that data is sent to the Node-Red GUI in the laptop computer from the Raspberry – Pi and displayed visually.
Python 2.7 Version with *Paho.MQTT* Library was used to establish the communication between the computer and the Raspberry-Pi. The data coming from the Air quality sensor was published to the topic *"Asthma/AIR"* from Raspberry – Pi. That topic is subscribed by the MQTT Server in the laptop computer. Then after doing the calculations, a decision was published to a topic called *"Buzzer"* from the MQTT Server installed in the laptop computer. The data coming from the Raspberry-Pi was graphically represented in the Node-Red GUI environment. We connected the Raspberry-Pi with the Laptop using a remote desktop connection in order to make it ease of accessing the Raspberry-Pi unit while avoiding the need of an extra LCD panel.

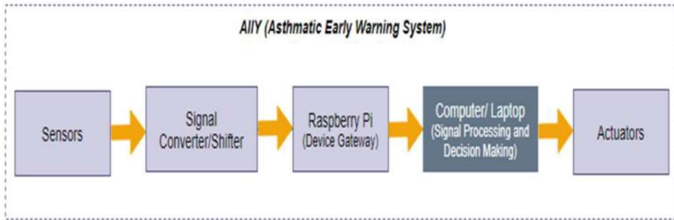

Fig. 10. High-Level Architecture of the System

3.4 Architecture of the System

AllY reads the humidity and air quality parameters by using DHT11, MQ2 and MQ135 sensors respectively. A logic level shifter (voltage level converter) is used to reduce the voltage from 5.0V to 3.3V since the operational voltage for air quality sensors should be 5.0V and for Raspberry it should be 3.3V. Signal converter is used to convert analog signals to digital (ADC-MCP3208). After generating the signals in the right voltage level, Raspberry is working as a gateway to receive the signals and pass to the laptop/computer (communication happened via topics) with the help of the MQTT protocol. ***Sensors*** are publishing topics through the MQTT broker hosted in the laptop/computer and ***actuators*** (SIM900A and the buzzer) subscribe to the relevant topic and actuate to the particular situation by ringing the buzzer and sending SMS.

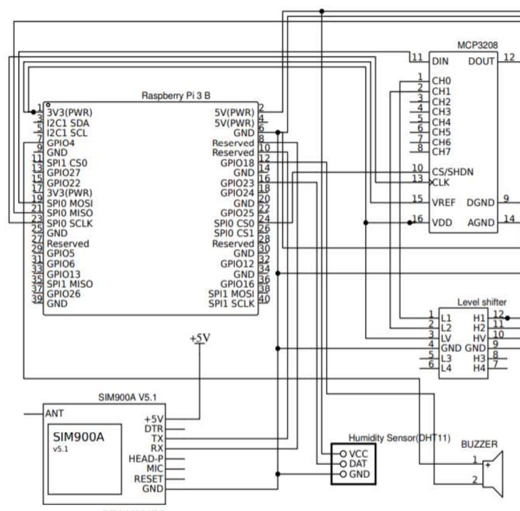

Fig. 11. High-level Circuit Diagram of the System

Sensor measurements are continuously read by a main Python program located in Raspberry Pi. Analog pins of the MQ sensors were used to obtain the levels of several gases. As analog data is not readable by the Raspberry Pi systems, those data were converted to digital format using MCP3208 analog to digital converter. The data flows from both sensors are handled by using two different channels of the same microcontroller. Since MQ sensors are operating with 5V and Raspberry Pi is operating with 3.3V logic level shifter was used to leverage the voltage coming from sensors before they send to the Raspberry Pi. DHT11 sensor operates individually and directly connected to Raspberry Pi which provides humidity and temperature readings. SIM900A communicates with the serial port of the Raspberry Pi and operates SMS messages using the AT commands. Buzzer is directly connected to a GPIO and configured a melody to play whenever a trigger is happened.

3.5 Operating the System

Figure 12 shows the implementation of the proposed system.

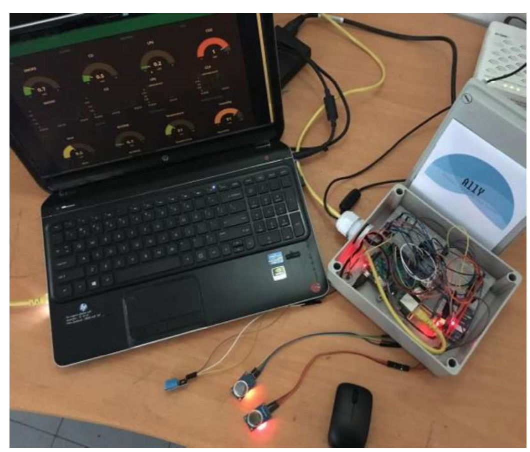

Fig. 12. System Implementation

The system consists of two continuously running Python programs. First one is used to extract sensor data from the three sensors (MQ2, MQ135 and DHT11) which is running on Raspberry Pi. Conversion of analog values to ppm also done by the same program. MQ Sensor datasheets provide guides to calculate ppm values by providing a (Rs/Ro) vs ppm graph [17] [18]. Ro value represents the value of resistance in fresh air and Rs means the value of resistance in Gas concentration. According to the directions from the sensor manufacturers, we developed the Python program to calibrate the sensor and extract the values of Ro in fresh air and then use it to find Rs using the below formula. [11][12].

$$\textbf{Resistance of Sensors (RS)} = (VC/VRL - 1) \times RL \quad (1)$$

3.6 System outputs

Sensor readings are visually represented using Node-Red tool as follows (Fig. 13).

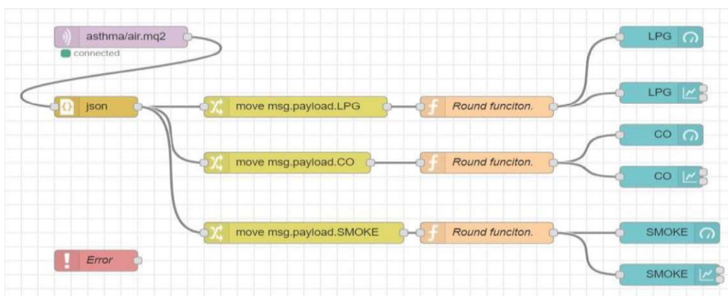

Fig. 13. Node-Red IDE

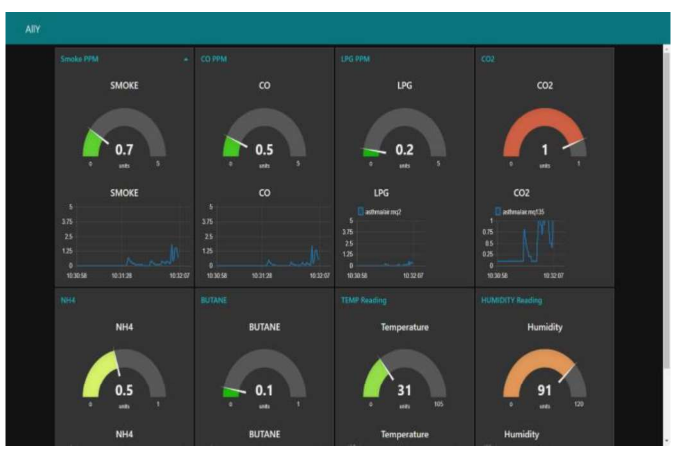

Fig. 14. Web Dashboard displaying operational sensor data

Both humidity and temperature data could be read directly from the data pin on DHT11 sensor which converts its own analog data to digital by itself [13]. The second Python program is responsible for receiving data from the Raspberry Pi and take the necessary decisions according to the gas levels. As the sensors send data continuously from Raspberry Pi, this runs as an infinite loop on the laptop computer. Sending and receiving of the data happened through the MQTT protocol. Decision making takes control from the laptop computer as it requires more processing power to do it in a fraction of time.

The real-time concentration of gasses are shown on a series of charts as on Fig. 14. Sensor measurements extracted during the daytime in outdoor conditions are shown in Table 1.

Table 1. Sensor Measures daytime outdoor

Air type	Expected value	Measured
Smoke (ppm)	0.1	0.08

CO (ppm)	95	92
LPG (ppm)	0.1	0.06
CO2 (ppm)	*420*	398
NH4 (ppm)	*45*	62
Butane (ppm)	*0.05*	0.06
Temperature (°C)	*17*	18
Humidity (RH)	*90*	95

Sensor measurements extracted during a rainy day indoor condition are shown in Table 2

Table 2. Sensor Measures during rainy day

Air type	Expected value	Measured
Smoke (ppm)	0.1	0.09
CO (ppm)	85	84
LPG (ppm)	0.1	0.06
CO2 (ppm)	*400*	372
NH4 (ppm)	*35*	54
Butane (ppm)	*0.05*	0.06
Temperature (°C)	*15*	16
Humidity (RH)	*105*	108

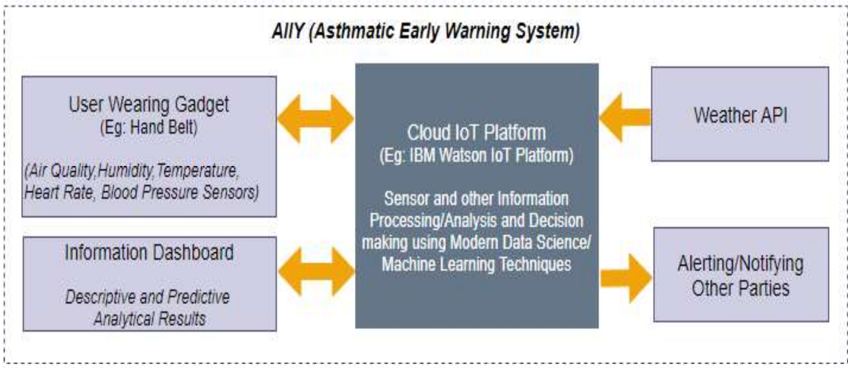

Fig. 15. Future Architecture of the System

4. Decision making process

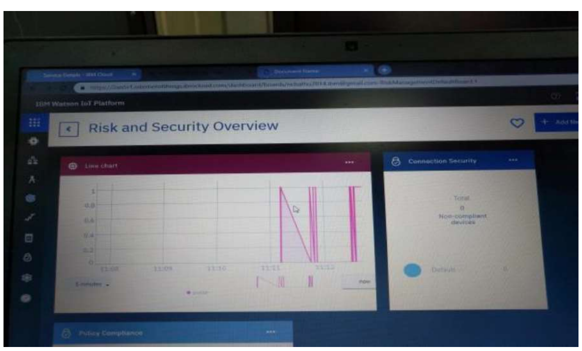

Fig. 16. Patient heart rate through IBM Watson IoT platform

In each and every environment the heart rate value of the patient pushes into the IBM Watson IoT platform for analysis. This streaming data can be accessed through Forecasting nodes [21] facility in IBM Watson platform to do the predicting the heart rate of the patient and it can be help to warn the relative parties.

Other decisions made with the help of ait type measurements. As you can see in the Table 1 and Table 2, recorded the sensor values for different environmental factors like how values for daytime outdoor and a rainy day. When each gas values are reaching the threshold values buzzer will rise up and alerting and sending SMS to the configured third party. In the experiment air type and heart rate mark as the feature list and asthma warning level can be labeled as Low, Medium and Critical. So we can use a deep learning model to do this classification.

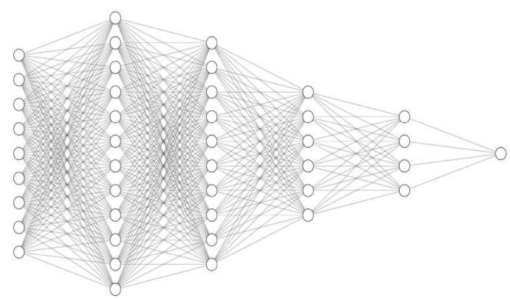

Fig. 17. Layer architecture of the deep classifier

5. Test results and validation

The results of the experiments were captured in terms of the number of values for true positive (TP), true negative (TN), false negative (FN), and false positive (FP), which subsequently were converted into overall accuracy, sensitivity, and specificity values as follows:

$$Accuracy = \frac{TP + TN}{TP + FP + TN + FN},$$
$$Sensitivity = \frac{TP}{TP + FN}, \quad Specificity = \frac{TN}{TN + FP}$$

A receiver operating characteristic (ROC) was used to characterize comparative performance of classifying algorithms for asthma exacerbation prediction resulting from different training data sets. The curve was created by plotting the true positive rate against the false positive rate at various threshold settings.

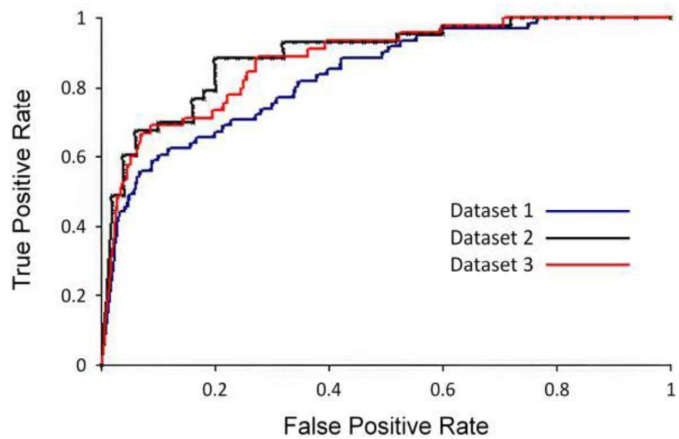

Fig. 18. AUC under ROC curve

Table 3. Evaluation of asthma prediction using deep learning classifier

Deep Learning Classifier			
Data Set	**1**	**2**	**3**
Accuracy	0.952	0.817	0.803
Sensitivity	0.455	0.860	0.844
Specificity	0.982	0.780	0.802

6. Conclusions and Future Works

Some possible future works of AllY is to convert the latter prototypical implementation as a real product that people can use in their own day to day life as a simple wearable gadget. There will be certain changes in the architecture as well as in the hardware and the platform. At the moment signal processing and decision making is done by a laptop/computer and there are no data analytics or machine learning involvement with the data to make some predictive outcomes. As per experimental level we have been able to get the patient's heart pulse rate using KY039 [19] sensor and push those reading into the IBM cloud, to IBM Watson IoT Platform [20]. In such a way we could improve the system by giving the power of prediction by collecting various kinds of data apart from current data (air quality, humidity) like heart (pulse) rate, blood pressure, and weather reports from accurate weather API's. Other than that directly making aware of the patient is also more important apart from using the buzzer and SMS. AllY will be able to identify the closest medical treatment center or other third party entity (E.g.: Ambulance service, Hospital emergency service, etc.) to make a notification and alert the relevant authorities. Other than that patient could refer the reports in daily manner and can take every steps in day-to-day life to be away or avoid from asthma like disease.

As the conclusion it could be said that our proposed, implemented and tested IoT based solution could early warn asthmatic situation to asthma patients by gathering sensor data (air quality, humidity and etc.) processing them and make some warnings to the patients and relevant authorities.

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