IoT Enabled Active Bio Filter for Indoor Air Quality Enhancement

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Abstract: Air Pollution has surged due to decades of swift industrialization and urbanization. With a majority of today's population spending most of their time indoors and the architecture of buildings made secluded from the outside environment, the importance of adequate indoor environment conditions has become advent. Indoor Air Pollution (IAP) has received little attention despite causing many diseases. Technology today has found its way into the day-to-day lives of humans and the Internet of Things (IoT) is one such. In this paper, we developed a system which checks the air quality of an enclosed environment for particulate matter (PM) such as PM1.0, PM2.5 and PM10.0, chemicals that can have an impact on our health like CO2, CO, O3, NO2, TVOC, CH2O and two physical parameters, temperature and humidity. This data is collected using NodeMCU and sent to a cloud server, this real-time data is reflected on an Android app for end user. The air quality of an enclosed environment degrades when the concentration of PM is high; when a certain threshold is reached another NodeMCU connected to the Bio Filter will receive the data from the server, switch the exhaust of the filter and push the polluted air to the snake plant to reduce the concentration of the air pollutants.

Keywords: IoT, Active Bio Filter, Air Quality, Air Pollution.

1 Introduction

Air Pollution is defined as any physical, biological, chemical change to the air. It may also be considered as the contamination of the air by harmful gases, dust or smoke which drastically affect the health of living beings. Decades of swift industrialization and urbanization has brought about a surge in air pollution, not only has it affected human health but also the Earth's climate.

In today's era, buildings are made to provide seclusion/protection from the outside environment. Buildings have now resorted to the use of mechanical ventilation like

© The Author(s) 2024
R. Murugan et al. (eds.), *Proceedings of the International Conference on Signal Processing and Computer Vision (SIPCOV 2023)*, Advances in Engineering Research 239,
https://doi.org/10.2991/978-94-6463-529-4_32

ceiling fans, air conditioners to recirculate indoor air. This has led to the accumulation of indoor air pollutants. There has also been strong evidence linking burning of solid fuels for cooking and heating towards IAP. The major types of fuel used for burning and heating are namely, wood, cow dung, coal, and charcoal [1-3].

In developing countries, people are likely to spend more time indoors so the importance of indoor environment conditions becomes apparent. Due to a lack of study pertaining towards the adverse effects of long-term exposure towards IAP, IAP has received insignificant attention as compared to outdoor air pollution. IAP is known to cause respiratory illnesses, viz., acute respiratory tract infection and COPD, poor perinatal outcomes like low birth weight and still-birth, cancer of nasopharynx, larynx, lung, and leukemia [4]. Apart from respiratory illnesses, IAP is also known to be a major player in increasing morbidity and mortality [5].

Technology has spread its roots to almost every corner in the daily lives of human beings. In the past decade, IoT has proven to us to be a major contributor towards communication. IoT has allowed us to connect physical objects (we call them 'Things'), exchange data between them over the internet. With this ability in hand, the development of intelligent devices and applications, and services become an easy task. IoT could be built on a sizable network of physical objects like sensors, actuators, mobile phones which can interact and cooperate with each other to reach a common goal [6]. In this paper, we propose a system to monitor the air quality of an enclosed environment the air quality in the presence of a Bio Filter while combining the domain of IoT.

2 Background

Air Quality is degrading due to the increase of harmful pollutants in the atmosphere and is a critical issue nowadays. There is an urgent need for an Air Quality Monitoring System so that appropriate methods can be implemented to reduce harmful pollutants, such as the use of filters. Multiple research was done from outdoor monitoring system to indoor monitoring system using IoT as the foundation. Kalaivani G et al.[7] presents detailed analysis on Air Quality (AQ) prediction and monitoring systems based upon IoT. This paper gives us a brief summary about the various Machine Learning (ML) techniques used to predict the air quality. After analyzing all the techniques, it was found that Random Forest is the best technique. Random Forest performed well for AQ prediction for data sets of varying size and location and having different characteristics.

Ramdevi M et al.[8] presents a system to measure the values of air quality, temperature, humidity and noise level. This system uses sensors MQ-3, DTH11 to gauge air pollution, temperature and humidity respectively and sound sensor, SEN-12642 for noise levels. These sensors transmit the values they collect to the microcontroller, NodeMCU. The Wi-Fi module of NodeMCU uploads the data collected to a cloud platform, Blynk which analyses the data and this data also gets transmitted to the user. If the values of air quality, temperature, humidity and noise level goes beyond the threshold levels, this system alerts users through email, messages, sound buzzer in case. Hassan MN et al.[9] presents a system used to measure temperature, humidity, and gas detection using sensors DTH22 MQ2, MQ4 and MQ135. The data collected by these sensors is transmitted to ThinkSpeak which is a cloud server. This data is then available for visualization to the user and also allows the user to set up a notification in case of any concerning change towards the sensor data. Faiazuddin S et al.[10] aims to create a system for remote monitoring of indoor air quality. This system uses a Raspberry Pi4 with Grove - Air Quality Sensor v1.3, CCS811 CO2 Air Quality Sensor, DHT 11 Temperature and Humidity Sensor. The sensors and Raspberry Pi4 communicate with each other through a serial port protocol, MQTT (Message Queuing Telemetry Transport). The data collected by the sensors is stored in a cloud platform, ThinkSpeak and data visualization is performed. Motlagh NH et al.[11] presents a process to capture air quality. The sensors used in this experiment are Generation 1 (G1) and Generation 2 (G2) which are portable, cheap and durable. These sensors can measure pressure, temperature, humidity, and PM2.5. It may also be noted that these sensors were placed in both outdoor and indoor environments and the results for both locations have been measured. Esfahani S et al.[12] in their paper talks about a system which uses IoT to monitor Indoor Air Quality (IAQ). This system consists of a group of low cost sensors interfaced using I2C, this array of sensors is controlled by a HUZZAH32 development microcontroller board. These sensors measure the Total Volatile Organic Compounds (TVOCs), Particulate Matter (PM), humidity, temperature and light of an indoor environment. In this array, a fan is also constructed which provides air flow through the entire system and sensors. The data collected by the sensor is collected and sent to the cloud server, Blynk using a Wi-Fi module. This data can be visualized, analyzed and downloaded by the user. Blynk also does the work of calculating the IAQ and provide suggestions for improving air quality in a mobile application Nasution TH et al.[13] designed and developed an indoor air quality monitoring system. This system monitors the concentration of dust particles and polluting gases (H2S, NH3, CO, NO2, and SO2), further ESP32 is used as the controller for acquiring the air particulate values and sending it over to ThingSpeak Cloud via Wi-Fi to monitor the data remotely. Jha RK et al.[14] proposed a system that monitors air quality in real time. The system utilizes IoT, therefore uses Arduino UNO as the microcontroller and sensors such as MQ7, MQ135 and dust sensor GP2Y1010AU0F for detecting CO, NO2 and PM2.5 respectively. The collected information is sent to ThinkSpeak Cloud via Wi-Fi through the use of ESP8266 module. An android app is developed in order to fetch all the air quality data via the ThinkSpeak Cloud. Kalia P et al.[15] in their paper proposed a portable device capable of sensing and measuring the concentration level of airborne Particulate Matter (PM) i.e. PM10.0, PM2.5, PM1.0 in the unit of lg/m3(microgram per metre cube) by PMS5003 sensor and also considers other environmental factors that include air moisture, dew point, humidity, temperature and barometric pressure this are measured using BME280 sensor. The air quality is measured in the unit of PPM (parts per million) via MQ-135 sensor. For the microcontroller NodeMCU ESP8266 is used which has Wi-Fi capability to upload the sensed data to ThinkSpeak Cloud. ul Samee I et al.[16] suggests a system that is low cost and monitors the air pollution levels, but unlike traditional sensor networks it is more reliable and has higher performance. In this study, they used IoT middleware architecture that is cloud-centric, which extracts data from both the built device as well as weather sensors. For ML an Artificial Neural Network was used and the level of PM2.5 and SO2 was predicted, this is done for forecasting of air pollutants level in future smart cities. ANN was found to be a reliable learning method for predicting air pollution level which is sensor based monitored data. Nigam H et al.[17] proposes an indoor environment sensing device that can sense and record indoor ambient surrounding data such as humidity, temperature, heat-index and chemical concentration of CO2 and CO. This system utilizes MQTT protocol which uses publisher subscriber model for transmitting data to Node-Red dashboard, it also sends emails and mobile SMS with the required information of indoor air quality. The data displayed in the dashboard include the Air Quality Index (AQI) along with the Heat-Index and this data gets updated when new data is recorded. Ayele TW et al.[18] worked on an IoT based device that not only monitors but also predicts air quality. This system uses a microcontroller ESP8266, DHT11 sensor and MQ135 gas sensor for monitoring the air quality. The microcontroller then is used to send the data to a web server where the data is stored. This data is further utilised by the LSTM (Long Short-Term Memory) algorithm for predicting as it reduces the training cycles with a good accuracy as it has a quick convergence.

3 Methodology

The system we proposed utilizes IoT to automate the task of controlling the Bio Filter for preserving good air quality in an enclosed environment i.e. labs, living rooms, health care room etc. This system can be deployed in an enclosed environment where the air quality is susceptible to deteriorate, places where the human footfall is high, offices where the air is stagnant most of the time, factories where workers come in contact with harmful gasses etc.

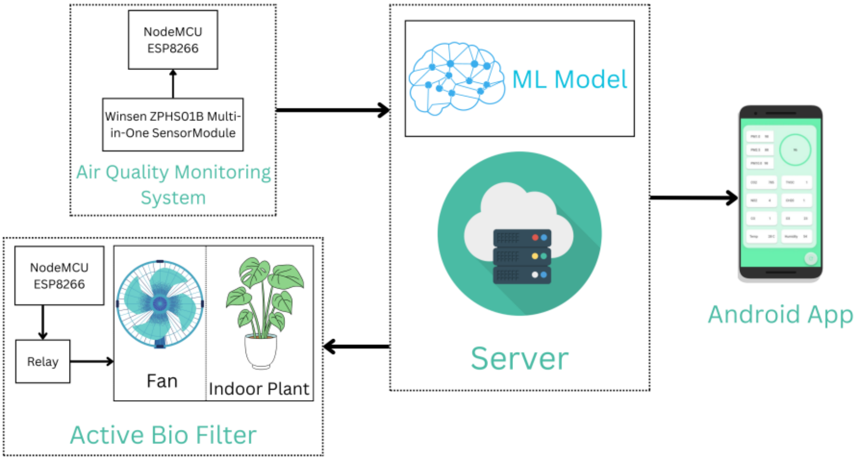

Fig.1.1. Architecture Diagram of the system

4 Materials and Methods

4.1 Air Quality Monitoring System

- **Microcontroller:** NodeMCU is used as the microcontroller in this prototype. The NodeMCU is connected to the sensor module which sense the environment and captures the Air Quality data. It is further programmed to send the captured data directly to the cloud that is Google Firebase. It is developed by ESP8266 Open Source Community, it's based on ESP8266 SoC (System on chip) made by Espressif System, supports wifi which is the the main reason that we selected the board for the air quality monitoring system.

- **Sensors used:** For the sensor we used Winsen ZPHS01B sensor module, this sensor can sense 11 parameters from the air as it is a sensor module that is an amalgamation of many sensors. The communication between the sensor and the microcontroller is via UART (Universal Asynchronous Receiver Transmitter) and the sensor module requires 5v dc input voltage. The various parameters the sensor module reads via various sensors and their specifications:

1. ***Winsen ZH06 III*****:** A laser dust sensor, the dust particles present in the air are detected via the laser scattering principle.

Technical Parameters	
Detection Range	0.3-10 µm
Effective Range	0-1000 µg/m³
Detection Interval	1 s
Preheating Time	30 s
Working Voltage	4.9V～5.5V(DC)
Working Current	＜120 mA
Detected Particulates	PM1.0, PM2.5, PM10.0
MTTF Continuous	> 10000 H

2. ***Winsen MH-Z19C*****:** It is a NDIR infrared gas module. The presence of CO2 is perceived through the Non-dispersive infrared principle.

Technical Parameters	
Detection Gas	CO2
Detection Range	400~5000 ppm
Preheat time	1 min
Working voltage	5.0±0.1V DC
Average current	< 40 mA (@5V power supply)
Peak current	125 mA (@5V power supply)
Lifespan	> 10 years

3. ***Winsen ZE08*****:** *It* is a general-purpose and miniaturisation sensor module that uses electrochemical principles to detect formaldehyde.

Technical Parameters	
Target Gas	CH2O
Interference Gas	Alcohol, CO etc
Detection Range	0～5 ppm
Resolution	≤0.01 ppm
Warm up time	≤3 minutes
Working Voltage	3.7V~5.5V
Working life	5 years (in clean air 18 ℃ ~ 25 ℃)

4. ***Winsen ZE27*:** Ozone detection sensor module in miniaturised form that utilises electrochemical principles.

Technical Parameters	
Target Gas	O3
Interference Gas	NO2, CL2 & etc.
Detection Range	0～10 ppm
Resolution	0.01 ppm
Working Voltage	3.7V～5.5V(No reverse voltage protection)
Warm up time	≤3 min
Working life	2 years (in air)

5. ***Winsen ZE07:*** An electrochemical carbon monoxide sensor module in miniaturised form.

Technical Parameters	
Target Gas	CO gas
Interference Gas	Alcohol and other gases
Detection Range	0~500 ppm
Resolution	0.1 ppm
Working Voltage	5V~12V (No voltage reverse connect protection)
Warm up time	≤ 3minutes
Working life	3-5 years (in air)

6. ***Winsen ZP07*:** A flat surface semiconductor gas sensor with good sensitivity to following volatile gases: formaldehyde, benzene, carbon monoxide, ammonia, hydrogen, alcohol and cigarette smoke of cigarette, essence & etc.

Technical Parameters	
Detection Gas	formaldehyde, benzene, carbon monoxide, hydrogen, alcohol, ammonia, smoke of cigarette, essence & etc
Working Voltage	5.0±0.2V DC (No voltage reverse connect protection)
Working Current	≤60 mA
Warm-up Time	≤3 min
Life Span	≥5 years

7. ***Winsen GM-102B***: A MEMS nitrogen dioxide gas sensor when the sensor is exposed to NO_2 gas the conductivity changes according to the concentration of the gas. Higher the concentration, higher the conductivity.

Technical Parameters	
Sensor Type	MEMS
Detection Gas	NO_2
Detection Range	0.1~10 ppm(NO_2)

The diagram given below, Fig: 1.2 depicts the circuit connection of our Air monitoring System where the NodeMCU and the Winsen ZPHS01B sensor module are connected via UART and are using a 5V power supply.

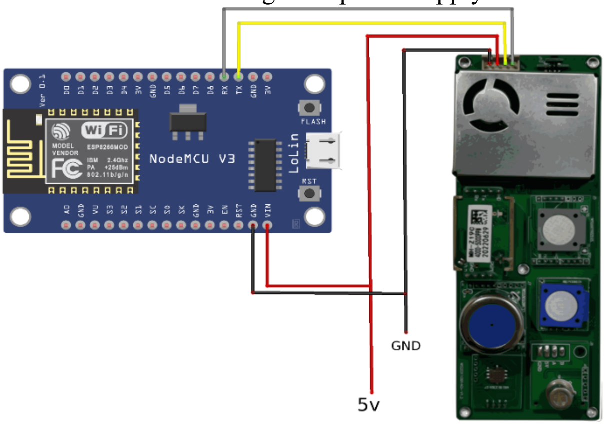

Fig.1.2. Circuit Diagram for Air quality monitoring system

4.2 Automatic Active Bio Filter

An Active Bio Filter is proposed in this work whose principal job is to purify and maintain the indoor air quality. It consists of different components such as an exhaust fan, air purifying plants, a microcontroller, and a relay. It is designed to collect the uncleaned air of a room using the exhaust mechanism to clean the indoor air and increase indoor air quality. This is also designed to work automatically as this just read air quality data of the room from Firebase cloud database which is being updated by the outer module connected to the sensor. If the air quality exceeds the threshold value then it automatically starts the Active Bio Filter. The following are the description of the components used to develop this filter:-

1. **Exhaust Fan -** The exhaust fan is to suck the air in the enclosed environment and feed it in the bio filter that has a snake plant inside it before letting it back to the ambient surrounding of the enclosed room/lab etc.

2. **Indoor Plants -** The vital element of the Bio Filter is indoor plants such as snake plant which purifies the air by absorbing the toxins from the air. It is can absorb most of the volatile components in the air and give out oxygen. An indoor plant doesn't require much maintenance and it serves as the Bio part of the Bio Filter.

3. **NodeMCU** - The microcontroller that have been used controls the relay of the Bio Filter when the air quality deteriorates and the data is fetched from the cloud database. It is developed by ESP8266 Open Source Community, it's based on ESP8266 SoC (System on chip) made by Espressif System, supports wifi which is the main reason that we selected the board for the air monitoring system.

4. **Relay** - An electronic switch that can be controlled via the NodeMCU for both ac and dc applications.

The circuit diagram for the Automated Active Bio Filter and the 2-D design of the structure of the filter have been provided below. In the circuit connection of Active Bio Filter where the NodeMCU receives signal from the cloud server and, according to the data received, switches the exhaust fan on or off via a relay that works as a switch from the power supply to the exhaust fan of the Bio Filter.

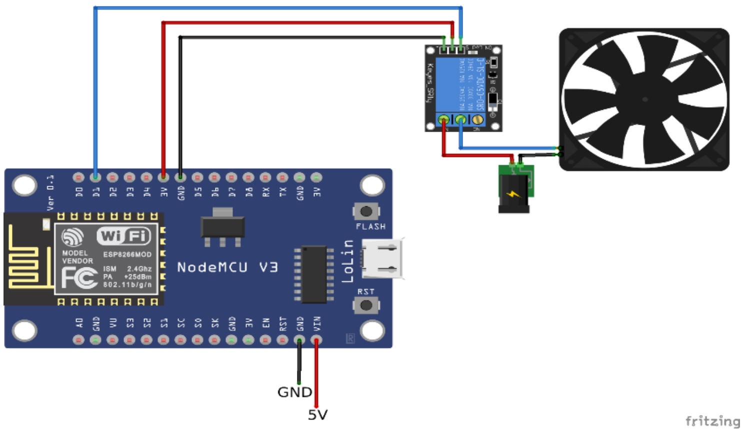

Fig.1.3. Circuit diagram for Automated Active Bio Filter

Fig.1.4. CAD image of the Active Bio Filter

5 Experimental Setup

The experimental setup consists of two modules in which one is used to sense the air quality data and the other is an automated active Bio Filter. In the previous section a detailed explanation of the sensor module and its technical details were provided. It primarily consist of Winsen ZPHS01B sensor which senses 11 air quality parameters (PM1.0, PM2.5, PM10.0, CO2, CO, CH2O, O3, NO2, TVOC, Temperature and Humidity) which is further uploaded to the Firebase cloud database. The other module is an Active Bio Filter which is designed to clean and maintain indoor air quality. The structure is made of wood and is shown in Fig 1.6. It consists of different components such as an exhaust fan, air purifying plants, a microcontroller and a relay. The microcontroller is coded to read the current values from Firebase cloud database. A threshold value is defined about various air quality parameter and if it exceeds the threshold then the microcontroller will activate the relay which turns on the exhaust fan. The structure of the filter is designed in such a way that the air that has been blown inside the Bio Filter is made to travel to different stacked chambers. Moreover, this sucked air is made exposed directly to the roots of the air purifying plants. By this mechanism the air cleansing mechanism works more effectively as compared to the traditional air purifying plants and Bio Filter.

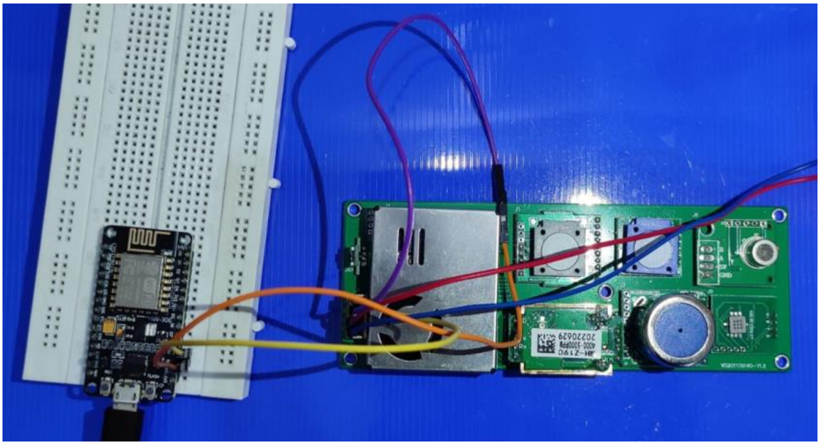

Fig.1.6. NodeMCU integration with sensor module

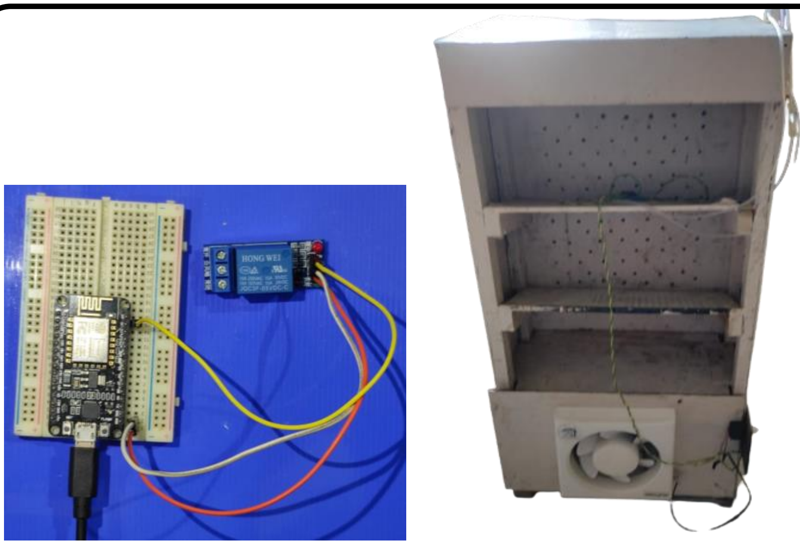

Fig.1.7. Controller of filter (left) and Wooden prototype of Automated Bio Filter (right)

In this work an android application has also been developed which is used to view all the 11 indoor air quality parameters used in this work. As the data related to corresponding parameters are uploaded to Firebase cloud database, this android application fetches all the data from there and displayed on an app like a dashboard. This provides easy access and monitoring of indoor air quality.

Fig.1.8. Screenshot of Android App to view data remotely

6 Results

The data captured by the sensor module were sent to the cloud storage from which the developed android application fetches those data and display it like in a dashboard. The data are collected at an interval of 30 minutes. By using the android application users can only view the last recorded data. From the cloud database a snapshot of the time series data has been displayed in Fig no. 1.8. Also the values of different Air Quality parameters are displayed in graphical representation in the following figures.

Date	Time	PM1.0	PM2.5	PM10.0	CO2	CO	CH2O	O3	NO2	TVOC	Temperature	Humidity
30-Nov-22	12:30 PM	209	255	271	5000	0.5	0.025	0.15	0.01	0	21	108
	1:00 PM	213	258	275	5000	0.5	0.02	0.04	0.01	0	21.4	107
	1:30 PM	220	265	283	5000	0.5	0.021	0.04	0.01	0	21.6	106
	2:00 PM	216	261	276	5000	0.5	0.023	0.05	6.04	1	21.7	106
	2:30 PM	207	253	269	5000	0.5	0.02	0.02	0.01	0	22	107
	3:00 PM	213	258	275	5000	0.5	0.021	0.04	0.01	0	21.6	107
	3:30 PM	216	261	278	5000	0.5	0.021	0.03	0.01	0	21.5	107
	4:00 PM	192	241	255	5000	0.5	0.021	0.03	0.01	3	21.4	106
	4:30 PM	152	176	192	500	0.5	0.021	0.02	0.01	0	20.7	109
	5:00 PM	34	42	47	1089	0.5	0.021	0.02	0.01	3	20.6	109
	5:30 PM	39	48	54	1087	0.5	0.022	0.02	0.01	1	20.4	110
	6:00 PM	42	53	58	1068	0.5	0.021	0.02	0.01	1	20.5	110
	7:00 PM	55	68	76	1079	0.5	0.022	0.02	0.01	1	20.5	110
	8:00 PM	55	68	77	1098	0.5	0.022	0.02	0.01	0	20.5	110

Fig.1.9. Snapshot of the data captured.

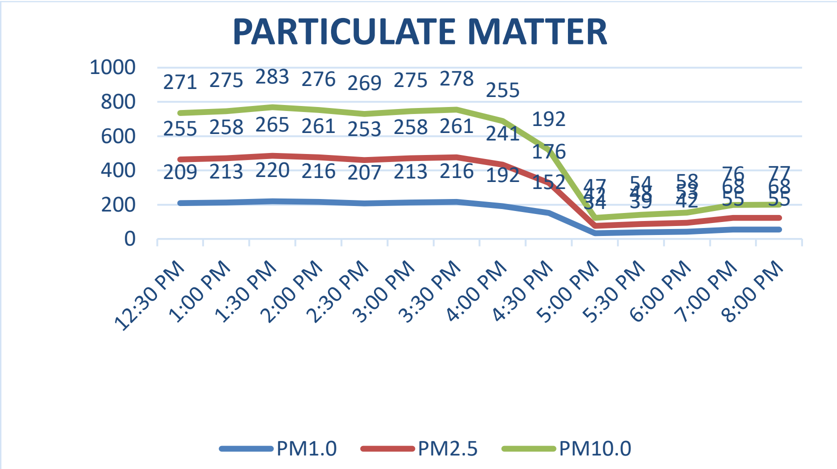

Fig.1.10. Graph for PM1.0, PM2.5 and PM 10 values.

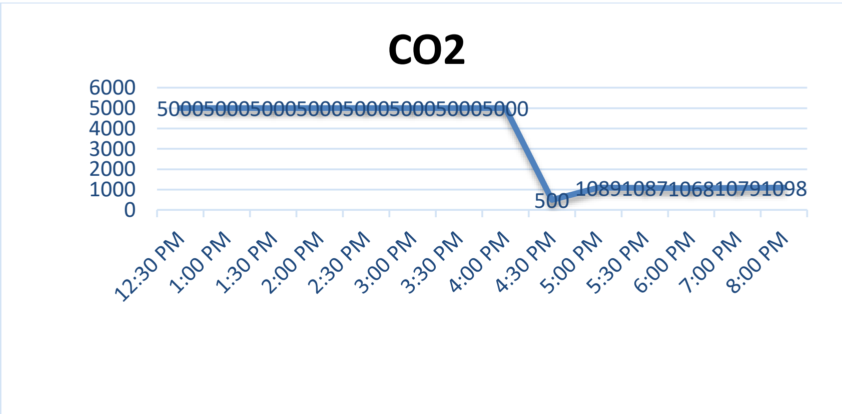

Fig.1.12. Graph for CO2 values.

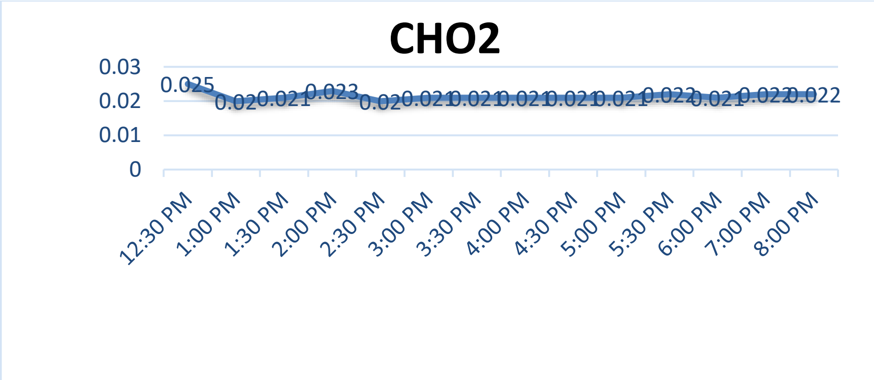

Fig.1.13. Graph for CHO2 values.

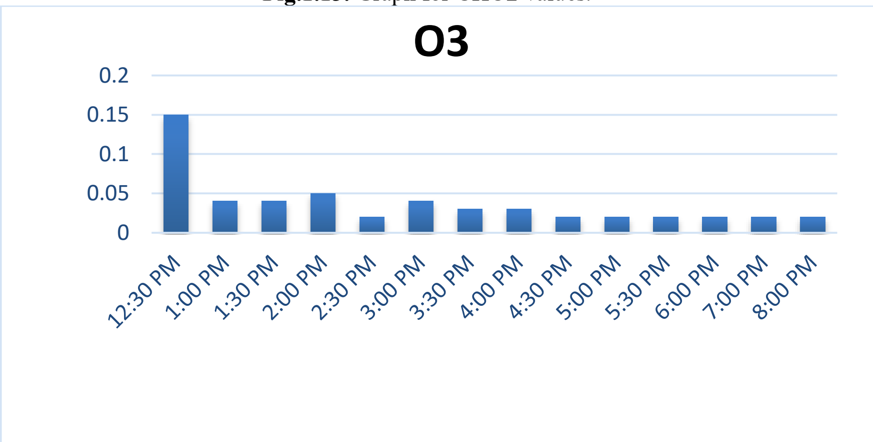

Fig.1.14. Graph for O3 values.

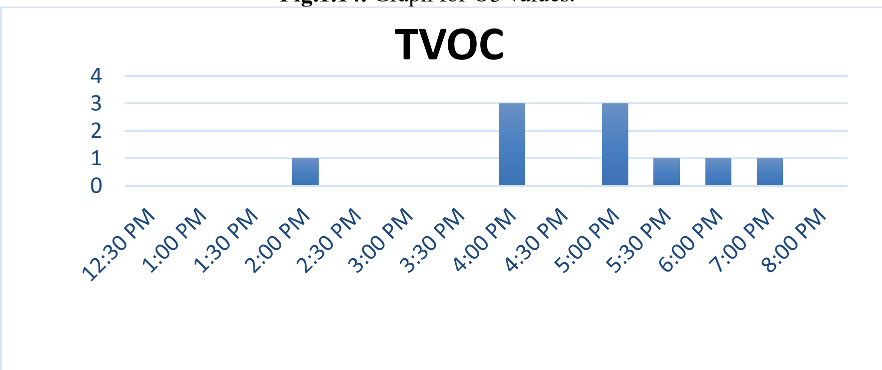

Fig.1.15. Graph for TVOC values.

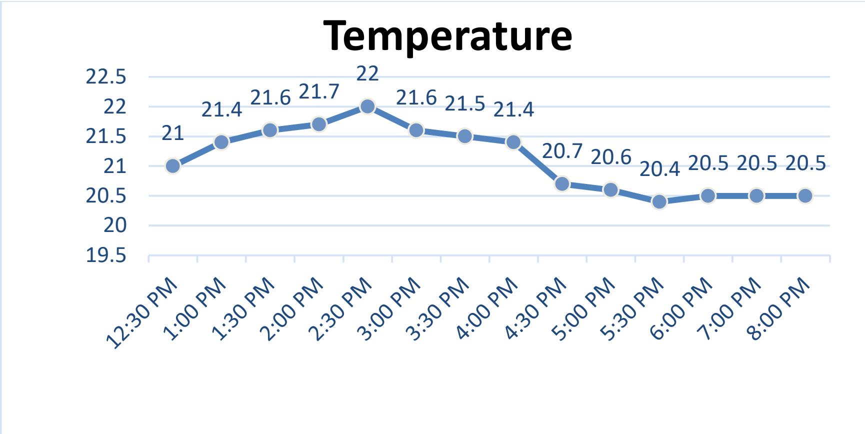

Fig.1.16. Graph for Temperature values.

7 Conclusion

In this paper, we propose a system for Air Quality Monitoring using IoT in the presence of a Bio Filter. The monitoring is done via NodeMCU connected to a Winsen ZPHS01B All In One – Air Quality Monitoring Sensor Module, it captures eleven different air quality parameters. The Bio Filter consists of a snake plant and an exhaust fan. This fan switches on when the air quality is poor depending on the sensed data and pushes the air toward the snake plant for cleansing purposes. The snake plant is a plant that is good at absorbing volatile and toxic components from air like formaldehyde, toluene etc. The future development includes the integration of ML for predicting and forecasting air quality, using an interface for data visualization and analytics and developing a fully-fledged android app with more features.

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