Cloud-based Low Cost Implementation of Real-Time Air Pollution Monitoring System

***Abstract*—Air pollution is a major threat to human health, and to the ecosystem which influences our everyday life. Emissions from vehicles, industries, and domestic sources are the main sources of air pollution. The first step to control air pollution is to develop a system to measure the level of pollution and the quality of air at a place where the air quality has to be monitored. Present IoT enabled automated monitoring stations are costly and not feasible for dense deployment over a wide geographical area. This work proposes the design and implementation of a low cost, efficient cloud-based IoT embedded system for real-time monitoring of air pollution using an embedded system of a sensor array. The developed system is low cost, low power, real-time, portable, battery-operated, and is suitable for monitoring the ambient air quality in a local area. The system is designed on three-layer IoT architecture. The data acquired by the sensors are uploaded in real-time to a remote cloud server for storage and analysis. The real-time sensor data and air quality information are made available through a web application. The measurements obtained from the system are calibrated and compared with the data air pollution monitoring stations**

***Index Terms*—Air Pollution, Sensors, Embedded Networks, IoT, Cloud computing**

I. Introduction

AIR pollution degrades the air quality and is a major concern all around the world for human beings and the ecosystem. Air pollution is the presence of gases, solid or liquid dust particles called particulates, or smoke in the atmosphere which makes harms to humans, animals, and our environment. According to WHO (World Health Organisation), air pollution is the predominant health problem for the citizen in many countries worldwide. Air pollution kills nearly seven million people every year [1]. More than 90% of the world population lives in places where AQI(Air Quality Index) level exceeds the safe level WHO limits [2]. Toxic gases such as Carbon Monoxide(CO), Nitrogen Dioxide(NO_2), Sulphur Dioxide(SO_2), Ozone(O_3), Greenhouse gases such as Methane(CH_4),Carbon Dioxide(CO_2), and particulate matters(tiny solid or liquid particles) namely PM2.5 and PM10 are the major air pollutants[3]-[4].

Vehicle exhaust fumes, exhaust from industries, and factories, natural causes, household activities, construction and agricultural activities are the major causes of air pollution. Air pollution is more severe in urban areas. Various measures are being taken all around the world against increasing ambient air pollution. The first step to control air pollution is continuously monitoring the pollution level and comparing it with the ambient air quality standards issued by authorities. CPCB (Central Pollution Control Board), SPCB (State Pollution Control Boards), PCC (Pollution Control Committees), and NEERI (National Environmental Engineering Research Institute) are the different organizations and agencies to monitor the ambient air quality of cities in India [5]. AAQMS (Ambient Air Quality Monitoring Systems) is the conventional type air pollution monitoring stations and require regular manual intervention and laboratory analysis. The device samples the ambient air for the defined target pollutants and that is collected manually and taken to the laboratory for analysis. Based on the analysis, the report is prepared manually and finally, the data is recorded in the server. The whole process takes more than 2 days to complete and to get the information about the pollution of the location. Real-time and continuous monitoring systems are the new trends in air quality monitoring globally. CAAQMS (Continuous Ambient Air Quality Monitoring Stations) is the advanced version of AAQMS. It uses gas analyzers and is housed in a temperature controlled room. It is implemented on IoT Technology for automatic data collection to the central server. It is a real time monitoring system and can generate, transmit and display pollution related information within minutes. CAAQMS reduces manual error as in the case of AAQMS. Presently there is a shortfall in the number of CAAQMS in India [6]. It is also very costly to install and maintain.

Many cities which are turning out to smart cities incorporate air pollution monitoring stations at different places and the measured data are published through various means [7]-[8]. The smart city is an urban area that uses different types of technologies, electronic methods, and sensors to collect data from the physical world. Thus low cost, reliable and real time air pollution monitoring system is an inevitable part of a smart city. "National smart cities mission" is an urban renewal and retrofitting program by the government of India with the mission to develop smart cities across the country making them citizen friendly and sustainable. The proposed air pollution monitoring system developed by using various sensors and IoT-cloud based efficient embedded network is an alternative for CAAQMS in the aspects of cost, power and maintenance. It is suitable for smart city applications for real time monitoring of ambient air pollution which helps in calculating the AQI (Air Quality Index) to issue health advisories as well as for the information of action plan to meet standards. The developed system has the advantages of real time pollution parameter visualisation from sensor data, real time AQI calculation and visualisation, low cost, low power, and require less maintenance. The system is battery operated and is portable also. Thus it can be deployed at any place easily. The proposed Air Pollution Monitoring System is functioning with an indigenously developed array sensor node which includes various sensors to collect information on ambient air pollution according to Indian air pollution standards and a cloud based embedded IoT network.

Sensor based air pollution monitoring system collects information that is related to different pollutants instantly through sensors based on MEMS (Micro Electro Mechanical Systems) technology having different working principles. Such low cost sensor based air pollution monitoring systems mainly use metal-oxide semiconductor type gas sensors, electrochemical type gas sensors, particle sensors known as PM (Particulate Matter) sensors working on the principle of laser scattering[9], and temperature and humidity sensors with solid state semiconductor sensing techniques, different wireless communication protocols for sending the collected data to remote servers, machine learning algorithms for prediction and analysis[10]-[13], and various types of APIs (Application Programming Interface) for user end interface. Moreover, the low cost and portable sensor based air pollution monitoring system with several units of sensor nodes can be easily deployed in any place where critical pollution affecting areas in a city. The air quality changes drastically over hundreds of meters, and therefore localized measuring systems for pollution monitoring are required. Therefore sensor based air pollution monitoring systems are getting more acceptance in the present scenario.

Different work done can be observed from the literature on the development of next generation air pollution monitoring systems all around the world by incorporating advanced sensing technologies, MEMS, WSN (Wireless Sensor Networks), LPWAN (Low Power Wide Area Network), IoT (Internet of Things), and cloud computing. Most of the work done is based on three layer IoT architecture and is found most suitable for the design of a new generation sensor based air pollution monitoring system to communicate to the people about the pollution level of the surroundings in real time.

The authors in [14] implemented an environmental monitoring system for indoor applications for monitoring pollutant gases in indoor air. This work uses a sensor array developed using electrochemical sensors and PIC microcontroller. The system is realised in *Labview* and this work is based on IEEE1451 standard for smart transducer interface for sensors and actuators for the sensor to processor communication.

The author's prototype in [15] is an energy efficient pollution monitoring system based on IEEE 802.15.4 low rate wireless personal area network (LR-WPAN) together with IEEE 1451.1 and IEEE 1452.2 interfacing standards. The authors implemented the system by developing a wireless smart transducer interface module (WSTIM) and wireless network capable application processor module (WNCAP) using PIC microcontroller and Zigbee module in addition to the array sensor node developed using electrochemical sensors.

The work done in the literature [16] is describing an air quality monitoring system based on IEEE/ISO/IEC 21451 standards for transducers interface with the communication system. In this work, 16 bit PIC microcontroller is used in the array sensor unit and M2M (Machine to Machine) wireless communication is realised through the GSM communication module. GUI (Graphical User Interface) was developed using MATLAB in this work for visualisation of sensor data.

The environmental monitoring system developed for Smart City applications by the authors in [17] uses the existing wireless sensor networks for the communication of sensor data. The creators developed both fixed and mobile sensor nodes and are deployed with the existing WSN. Different types of sensors including PM2.5, PM10 and gas sensors for NO_2, SO_2, O_3, CO are used in sensor nodes along with auxiliary parameters such as temperature, humidity, wind, and pressure. This work excluded electrochemical sensors due to their short life span.

The design and evaluation of air pollution sensing system by the creators in[18] is a low-cost participatory sensing system. This method uses portable mobile sensing units, smartphones with 3G capability, cloud computing, GPS and mobile apps for sensor data uploading to central server. This work is based on crowd sourcing or participatory sensing by collecting and contributing air pollution data obtained from personal sensing units. Sensor data visualisation is web based with a developed web application for this system.

The work done by authors in[19] is a low cost distributed air pollution monitoring system that uses a sensor node which contains mainly particulate matter sensor PMS3003 to collect the information about the pollution caused by PM2.5 and PM10 along with temperature and humidity sensors. This system periodically collects the pollutant information and uploads it to a central open source database over MQTT protocol using the existing Wi-Fi network in their city.

The literature in [20] describing a system for monitoring air pollution in urban areas with machine learning based forecasting models. The authors proposed low cost air quality monitoring motes which are equipped with an array sensor containing gaseous and meteorological sensors. The network architecture is based on the GSM M2M(Machine to Machine) communication protocol. Forecasting models for gaseous pollutants such as ground level O3, NO2, SO2 using three different machine learning algorithms is another feature of this work.

A low power WAN (Wide Area Network) based design for air quality monitoring can be found in [21]. The system monitors the concentration of PM2.5 using a PMS5003 sensor and an ARM based controller. The LPWAN is based on IEEE802.15.4K standard and is implemented using SDR(Software Defined Radio). The data stored in the author's cloud and user end interface is provided by using the web and mobile apps.

Electrochemical sensors, and NB-IoT network communication over TCP/IP protocol implementation can be found in the air quality monitoring system design in [22].

The remaining sections of this paper is organised as follows. In section II, implementation of the proposed air pollution monitoring system is detailed. The measurement of air pollution data, its transmission, and cloud server configuration for the storage of sensor data are discussed in section III. Section IV is detailing with the measured data of pollutants and their comparison with known standards. Finally, conclusion is given in section V.

II. Implementation of Air Pollution Monitoring System

The overview of the proposed method of Sensor-IoT-Cloud based air pollution monitoring is shown in figure 1.

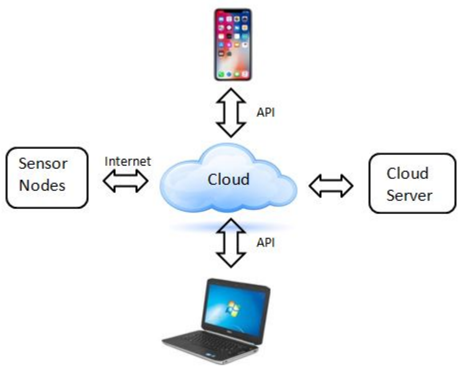

Fig. 1: Overview of air pollution monitoring system.

The proposed system of air quality monitoring goes through the following stages.

Stage 1 : Recognise the concentration of polluting gases in the selected area by means of suitable sensors in the sensor node. A sensor node consists of a sensor (sensors), a micro controller, and a communication unit. The proposed system is implemented by developing a sensor array unit as the sensor node.

A typical sensor node is shown in figure 2.

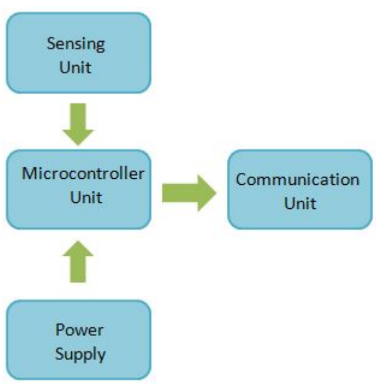

Fig. 2: A Typical sensor node.

Stage 2 : Read and preprocess the sensor data using a micro controller

Stage 3 : Send the sensor data to the cloud server through a suitable network and store the time series data in a database.

Stage 4 : Build up an easy to understand and convenient interface - a web application or an API which the client can use to know the pollution level of their surroundings.

Stage 5 : After the analysis give the concentration of pollutants present and give the air quality index.

A. General Design Considerations

Our college campus is situated in an industrial area and is surrounded by many industrial units. This place is also one of the highly polluted areas in the state. Thus the air quality is suspecting degraded. We formalize the necessity and requirements for a low-cost solution for determining the concentration of air pollutants and continuous air quality monitoring by considering 1) Low cost but reliable sensors 2) Lightweight and compact form factor 3) Wireless connectivity and 4) Ease of deployment

The entire system is the implementation of an efficient IoT embedded network based on three layer IoT architecture [23] as shown in figure 3 .

Fig. 3: Three layer IoT architecture [23]

The three layers are the perception layer also called the sensor layer, the network layer, and the application layer. The perception layer is the physical layer that includes the end devices, sensors, microcontroller, and a communication unit. The required information is gathered from the physical world by this layer. The role of the network layer is to transmit and process the data acquired from the perception layer. The network layer connects the devices in the perception layer to other smart objects, remote servers and network devices. It is also responsible for the transmission of the whole data. The application layer is responsible for user interaction. It is responsible for delivering application related services to the end user. This can be achieved through a web application, android application or an API (Application Programming Interface).

The proposed system is designed with four Types of sensors: 1)A low cost PM sensor to detect the suspended particles such as PM2.5 and PM10 which are the major pollutants in many areas, 2) Low cost metal oxide/ electrochemical type gas sensors to detect the toxic gases like NO_2, SO_2, CO, etc., 3) Gas sensors to detect greenhouse gases such as CH_4 and CO_2 4) Temperature/ Humidity sensor. Wi-Fi communication is the most practical solution against other Communication protocols such as Zigbee or LoRa because almost the entire college campus area has Wi-Fi connectivity so that the sensor nodes can be easily made as an IoT device by connecting the sensor nodes to the internet over Wi-Fi through routers. Also, Wi-Fi enabled MCUs like NodeMCU are less expensive than the other alternative RF solutions.

B. Implementation

For the efficient implementation of the proposed air pollution monitoring system we designed an efficient IoT embedded network with cloud computing. The implementation block schematic is shown in figure 4. The detailed system architecture of the proposed Cloud based IoT Embedded Network with a single Array sensor node is illustrated in figure 5.

The array sensor node containing 11 sensors, and a microcontroller with a Wi-Fi access point is the end device of the IoT system. The sensor array includes metal oxide type and electrochemical type gas sensors to acquire information about polluting gases, Particulate matter(PM) sensor (PMS5003) to collect the data about the predominant pollutants such as PM2.5, PM10, and PM1.0, temperature and humidity sensor.

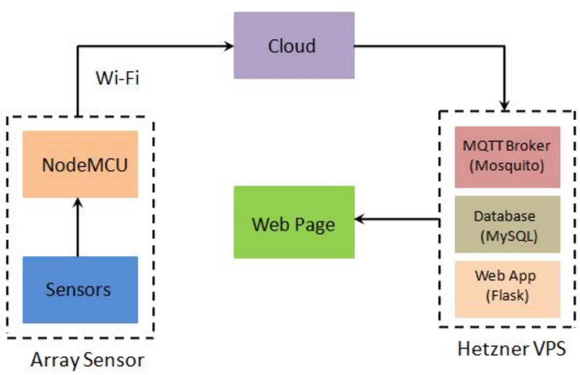

Fig. 4: Implementation block diagram.

NodeMCU is used as the microcontroller and communication unit for the sensor array node. NodeMCU is a low cost open source IoT platform and it includes firmware that runs on ESP8266 Wi-Fi SoC (System on Chip) and the hardware which is based on ESP12 or ESP32. NodeMCU supports MQTT(Message Queuing Transport Telemetry) IoT protocol and can access the MQTT broker in the cloud server for publishing the acquired sensor data. NodeMCU communicates with the Internet cloud over Wi-Fi protocol. The sensor data are published to the Mosquito MQTT broker in the remote cloud server in JSON (Java Script Object Notation) data format which is a lightweight data format.

C. Sensors

A sensor is a device that measures physical quantity from the surroundings and converts it into to meaningful data that can be interpreted by either a machine or human. Most of the sensors convert the physical quantity into an electrical signal. A gas sensor is a transducer that converts the concentration of detected gas molecules to corresponding electrical signal magnitude. Gas sensors are not 100% sensitive to a particular gas but with the advanced sensing and fabrication technologies gas sensors with less cross sensitivity and improved performance are came into the picture. Commonly used technologies for gas sensors are solid state(metal oxide semiconductor), electrochemical, infrared, photoionization, and catalytic bead [24]-[26]

1) Metal oxide semiconductor sensors:

Metal oxide semiconductor gas sensors are low cost sensors. These types of sensors detect the concentration of target gases by measuring the changes in resistance of the metal oxide layer such as Tin Dioxide (SnO_2) when it is heated due to the adsorption of gases [27]. Atmospheric oxygen on the sensing layer surface is reduced by the target gases and hence more free electrons in the conduction band of the metal oxide sensing material. Metal oxide type sensors are available for a wide range of gases and normally they are sensitive to more than one gas. Multi element gas sensor array in a single chip is a recent development in metal oxide sensors [28]. For the gases CO_2, CH_4, NH_3, and O_3 we used Metal Oxide Sensors. MOS sensors require a simple external circuit in order to measure the concentration of target gas. Figure 6 shows a simple circuit that we use to convert the resistance change of sensing material into voltage. Metal oxide sensors are smaller as well as cheaper than electrochemical type gas sensors but are non linear, temperature, and humidity dependent. Hence temperature and humidity sensors are commonly used with metal oxide sensors to calculate temperature, and humidity compensated gas concentration values in many air pollution monitoring systems[29].

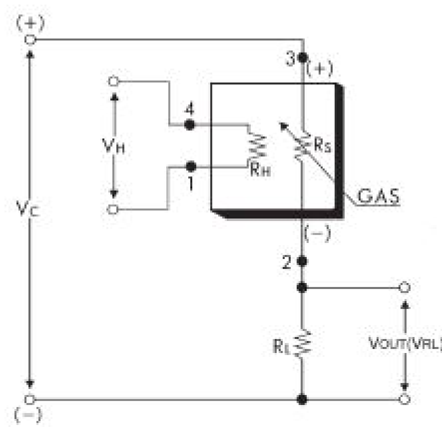

Fig. 6: Metal oxide sensor measuring circuit.

V_H is the heater voltage and Vc is the circuit voltage. The heater is used to maintaining the sensing material at a specific temperature which is optimum for sensing. Circuit voltage Vc provides the measurement of voltage ($Vout$) across the load resistance (R_L). R_L comes in series with the sensor resistance Rs. The resistance of the sensing layer(Rs) of metal oxide semiconductor type sensors decreases with an increase in the concentration of target gases. They offer maximum resistance in clean air. The sensor resistance Rs and load resistance R_L form a potential divider. V_{RL} is the sensor output voltage proportional to the gas concentration when Vc is applied across the potential divider formed by Rs and R_L

The sensor resistance Rs is obtained as

$$Rs = \left(\frac{Vc}{V_{RL}} - 1 \right) R_L \tag{1}$$

and the gas concentration in ppm is

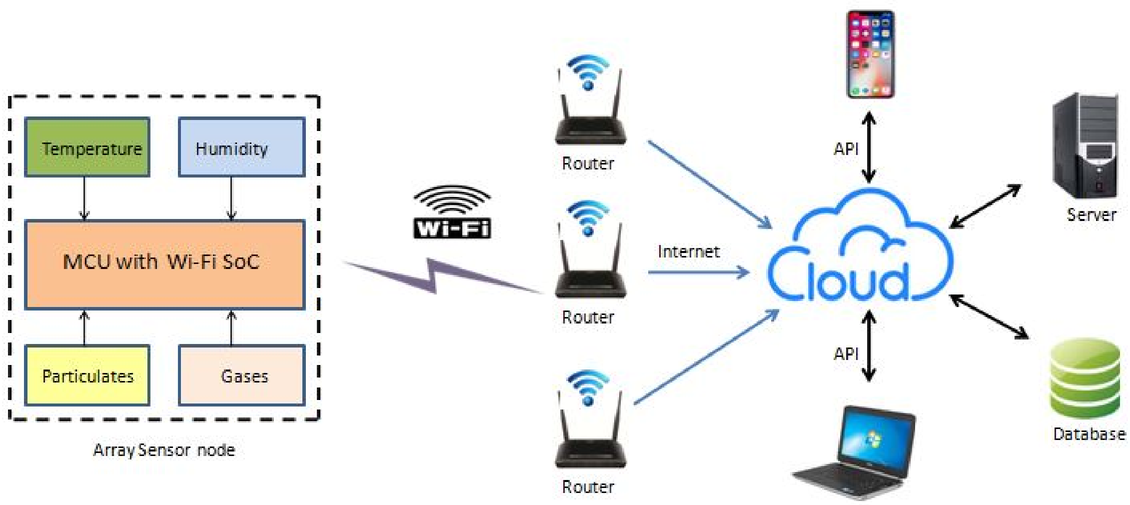

Fig. 5: System Architecture of the proposed IoT Embedded Network with a single Array sensor node

$$ppm = \frac{Rs}{R_0} \tag{2}$$

where
R_0=Resistance at 0 ppm of target gas
Data sheet of sensor gives the sensitivity characteristics showing the variation in Rs/R_0 ratio with gas concentration in ppm

2) Electrochemial Sensors:

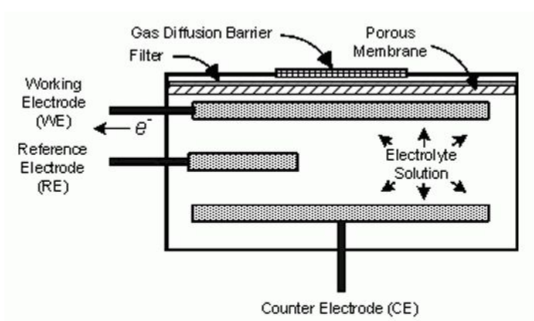

Fig. 7: Basic Electrochemical Sensor

Electrochemical type gas sensors measure the concentration of target gases by oxidizing or reducing the target gases at the electrode called the working electrode and producing a resulting current [30]. A basic electrochemical sensor is shown in figure 7. The gases are allowed to diffuse through a porous membrane to the working electrode. Electrochemical type gas sensors produce a current proportional to the target gas concentration. The electrochemical gas sensors can detect different gases with good accuracy. These sensors have an important advantage of minimum power consumption over other types of sensors. Since they generate current, before connecting it to the ADC, the generated current has to be converted to an equivalent voltage by using a current to voltage converter. In this work CO, NO_2, SO_2, and H_2S sensors used are the electrochemical type. Figure 8 shows the measuring circuit of CO sensor TGS5042.

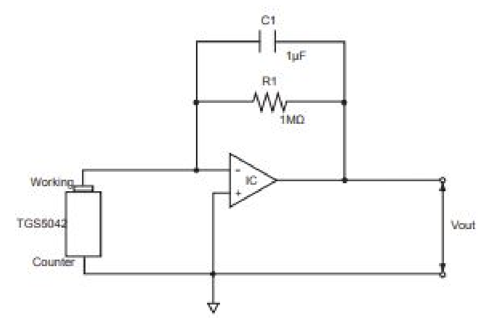

Fig. 8: Measuring circuit of CO sensor TGS5042

The gas concentration will be obtained from the formula

$$Gasconcentration = \frac{Vgas - Vgas0}{M} \tag{3}$$

where
$Vgas$= $Vout$ at gas level,
$Vgas0$= $Vout$ at 0 gas level,
M= sensor calibration factor.

3) Particulate Matter(PM) Sensor:

Atmospheric particles are the major pollutants in many countries. In real time monitoring systems for atmospheric particles the particle concentration data of PM1.0, PM2.5, and PM10 are collected. Low cost Particulate Matter(PM) sensor is working on the principle of laser scattering. The laser is scattered to radiate suspended particles in the air. The scattered light is collected certain degree and the curve of scattered light changes with time is obtained. Then the equivalent particle diameter and the number of particles with different diameter per unit volume is calculated by a microprocessor based on 'Mie' theory.[31]. *Plantower* PMS 5003 particle sensor is used in this work which provides calibrated PM1.0, PM2.5, and PM10 output. The internal block diagram of PMS 5003 is shown in figure 9.

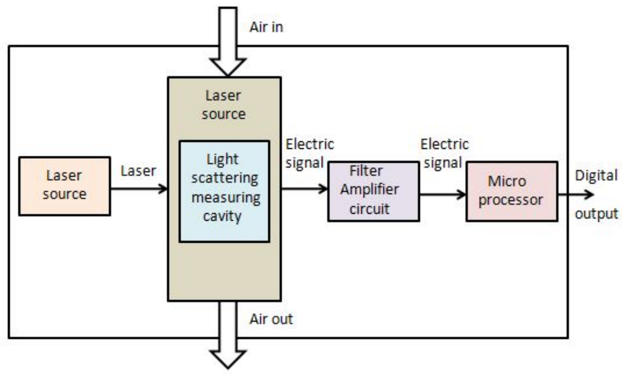

Fig. 9: Block diagram of PM sensor based on light scattering

D. Development of Array Sensor node

The sensor node is the most important unit of any air pollution monitoring system. The sensor node includes different types of sensors for acquiring air quality related information from the ambient air, a microcontroller unit to read and preprocess the acquired raw data from the sensor, and a communication unit to transmit the collected data to a remote server. The sensor node for this work is designed and developed as an array of various types of sensors. An array sensor is a group of sensors deployed in a specified geographical area to detect the concentration of pollutants. The developed array sensor unit which is the key part of the proposed air pollution monitoring system is shown in figure 10. The array sensor unit is fabricated by using different types of sensors such as metal oxide type gas sensors, electrochemical type gas sensors, particulate matter sensor, temperature, and humidity sensors. Using this array sensor which contains 11 sensors, 14 parameters (including AQI) related to air quality are monitored. This developed sensor node has unique advantages of low cost, low power, lightweight, portable, and battery operated. therefore, it can be easily deployed at any place.

The details of sensors used in the array are shown in the table I

The sensors to detect Carbon dioxide (CO_2), Ammonia (NH_3), Methane (CH_4), and Ozone (O_3) gases used in the array are of Metal oxide type, Whereas Sulphur Dioxide(SO_2), Nitrogen Dioxide(NO_2), Carbon monoxide(CO), and Hydrogen Sulphide(H_2S) gas sensors are of Electrochemical type.

The interfacing diagram of sensors with Nodemcu is shown in figure 11

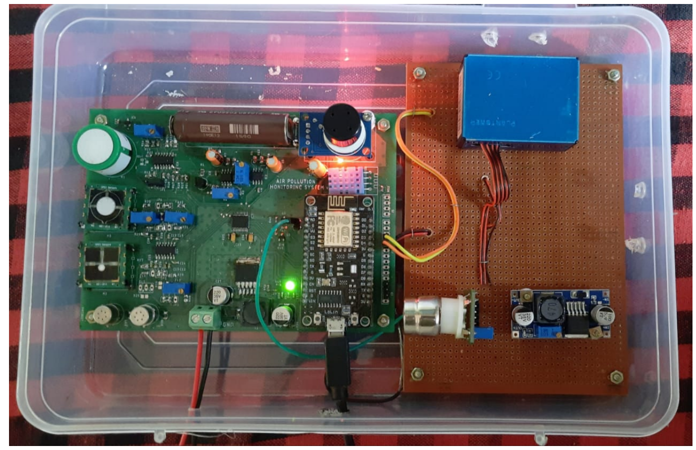

Fig. 10: The developed array sensor node

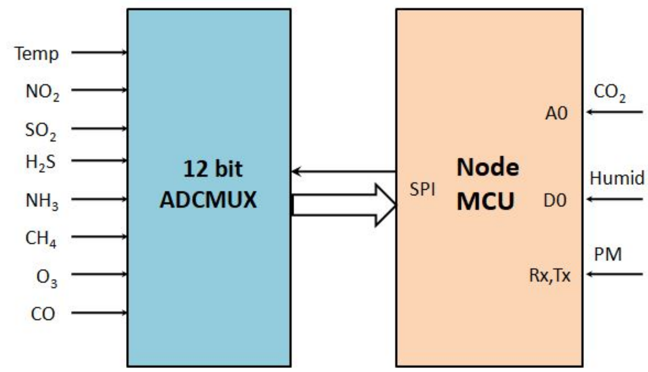

Fig. 11: Sensor Interfacing with Nodemcu

The MQ811 CO_2 sensor is connected to the analog pin A0 of nodeMCU and the analog output voltage of the sensor is converted to equivalent digital value through the 10 bit built-in ADC of nodeMCU. Digital value equivalent to the analog output voltage of the sensor is then converted into the gas concentration in ppm(parts per million). DHT11 is the humidity sensor used which is interfaced through one wire interface protocol and is conducted at the D0 pin of nodeMCU. *Plantower* PMS5003 is the PM sensor. PMS5003 provides a calibrated digital output of PM1.0, PM2.5, and PM10 in UART(Universal Asynchronous Receive Transmit) serial data format. This serial data is read through the serial interface pins of nodeMCU. The sampling rate of PMS5003 is around 1Hz. The sensor uses a photo transmitter and receiver pair with the light scattering principle to get particle counts and convert these concentrations into $\mu gm/\mathrm{m}^3$.

The analog output voltages from the other eight senses are converted to 12 bit equivalent digital value using an external ADC multiplexer ZADCS147 and are interfaced with nodeMCU through the SPI(Synchronous Peripheral Interface) port.

III. Cloud Storage of Measured Data

The Air pollution monitoring system is developed with an intention to deploy in our college campus since our college is situated at "Mangattuparamba" which is a main industrial

TABLE I: Details of Sensors used in the array sensor unit

Target Gas(Pollutant)	Sensor name	Type	Range
Temperature	TC1047	Semiconductor	-40°C to +125° C
Humidity	DHT 11	Semiconductor	20% to 90%
PM1.0,PM2.5,PM10	PMS5003	Optical scattering	0-500 $\mu gm/\text{m}^3$
Carbon Dioxode(CO_2)	MQ811	Metal Oxide	350-10000ppm
Ammonia(NH_3)	TGS 2602	Metal Oxide	1-30ppm
Methane(CH_4)	TGS 2600	Metal Oxide	1-30ppm
Ozone(O_3)	MQ 131	Metal Oxide	0-1000ppb
Nitrogen Dioxide(NO_2)	SPEC-3SP-NO2	Electrochemical	0-5ppm
Sulphur Dioxide(SO_2)	FECS 43-20	Electrochemical	0-20ppm
Hydrogen Sulphide(H_2S)	SPEC-3SP-NO2	Electrochemical	0-50ppm
Carbon Monoxide(CO)	TGS 5042	Electrochemical	0-1000ppm

area in the State and is also a fastly urbanizing municipal township. Our college campus is a smart campus with wireless internet access all around the campus area through many Wi-Fi access points. Thus Wi-Fi based WSN (Wireless Sensor Network) implementation is cost effective by using the existing Wi-Fi network resources. Comparing with WSNs based on other wireless communication technologies [32]-[34], Wi-Fi wireless networks have significant advantages of high bandwidth, non line of sight transmission, large coverage area, easy expansion of nodes[35]. In our system, hardware cost is reduced considerably by using the existing Wi-Fi network and also by incorporating *NodeMCU* in the array sensor node, which is a low cost built in Wi-Fi SoC (System on Chip) micro controller chip.

Nodemcu is an open source firmware developed on *Lua* scripting language which supports Wi-Fi access integrated with ESP8266 Wi-Fi SoC with TCP/IP Protocol[36]. It is a very low cost and highly featured device which makes it an ideal module for IoT applications. It is suitable for any applications that are required to connect a device or thing to a local network or to the internet through a Wi-Fi router. NodeMCU uses a lightweight on module flash based SPIFFS(Serial Peripheral Interface Flash File System) file system. Another important feature of nodeMCU which makes it ideal for IoT applications is that it supports the MQTT IoT protocol and can access the MQTT broker in the server.

A. Cloud Server Configuration

The Configuration of cloud server for the implementation of the system is shown in figure 12

Locally collected data by the sensors in the sensor node is transferred to the MQTT broker over the MQTT protocol. The mosquito MQTT broker is hosted in the cloud server. The reason for choosinge the MQTT protocol is that it is a lightweight messaging protocol in which officers simple machine to machine communication through a standard internet connection through the MQTT broker which acts as centralised node. The sensor node sends data packets periodically as topics which contain the device's IP address, timestamp, sensor name, and sensor value.

'Hetzner'VPS (Virtual Private Server) is the cloud server used for this work. The Hetzner VPS is configured as a *PaaS*(Platform as a Service). *PaaS* are cloud based platforms that allow us to build, run, and operate applications in the cloud with built in software components that help to create, run, and scale applications quickly, easily, and cost-effectively. The server management is done by *CapRover* which is an easy to use web server management tool. Three docker containers are created in the server. Docker is an open source software platform or tool for building, deploying, and running applications based on containers. By using a container, all the required libraries and other dependencies required to run an application are enclosed as a single package for deployment allowing them to be portable among any system.

In the first container 'Mosquito' which is a popular open source MQTT broker written in C is installed. Certificate based client authentication is used with the Mosquito MQTT broker. For this, self signed client certificates are generated for the client and the server. The client and server must use the same CA(Certificate Authority) and the broker needs to use SSL(Secure Socket Layer) for secured connection. SSL is the standard technology for secured internet connection and security of data that is being sent between two systems. This is because client certificates require an encrypted connection for data security. The generated client certificate, client key(private key), and CA key are uploaded in the EEPROM of nodeMCU in the sense node before uploading the Arduino sketch for sensor data uploading. The root CA certificate from the same certificate authority is attached with the MQTT broker which is located in the first docker container. TLS(Transport Layer Security) is more secured and is an updated version of SSL. The secured connection between broker and client(sensor node) is ensured by using TLS version 1.3.

In the second docker container, a 'PAHO' Python client is created and installed as the MQTT client for subscribing the published sensor data from the sensor node to the MQTT broker in a specified topic. Topics are a form of addressing which use UTF-8 strings and allow MQTT client to share information. From the received topic, the sensor data are extracted and stored in a database. An open source Python framework

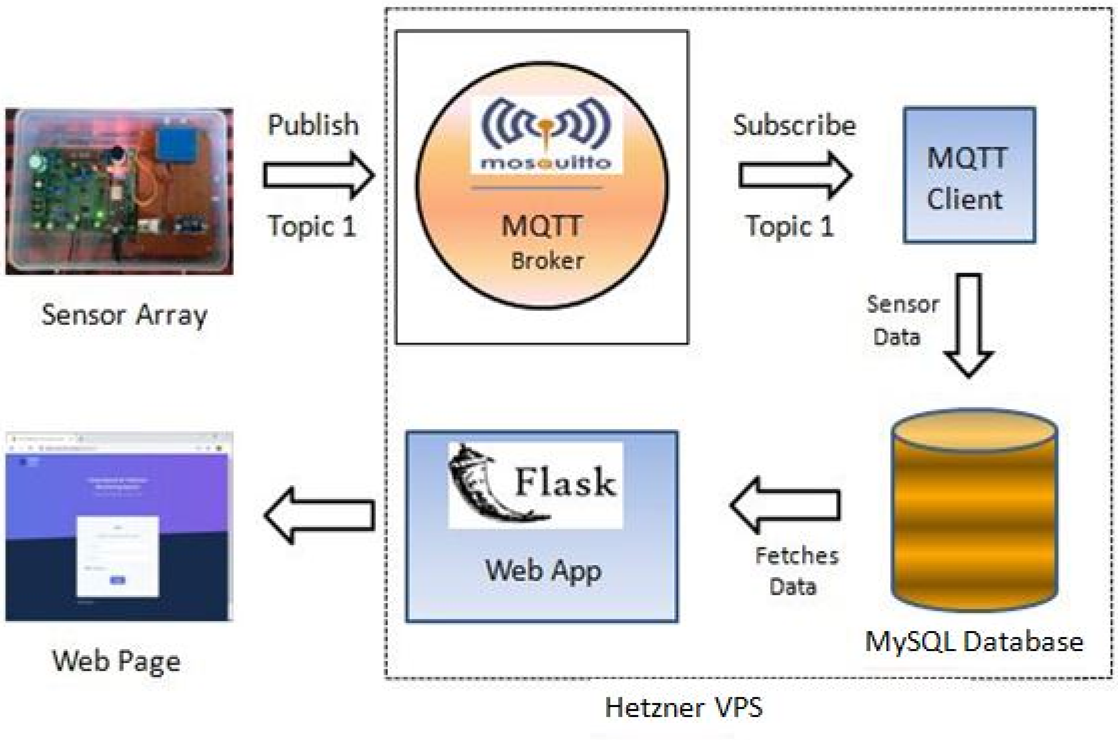

Fig. 12: Cloud Server Configuration

'flask' is also running at the second docker container. 'Flask' is a lightweight web application microframework for the back end of the web application. When anybody browses the web page, the flask fetches the data from the database and displays in the web page.

The third docker container is used for the database. 'MySQL' a free and open source database is used for this work. Tables are created in the database to store the sensor data in the order of sensor name, time, and value. Data stored in MySQL database can be visualized and retrieved using *PhpMyAdmin*. *PhpMyAdmin* is a free PHP tool that helps us with an interface to work with MySQL database. We can easily modify, create or delete records using this tool and also import and export tables from the MySQL database.

B. Web based User Interface

A web application is developed on *flask*, a Python based open source framework for web application development for real-time visualisation of sensor data and analysed results. The web application has two components: a client-side component and a server-side component. As mentioned earlier, the server stores the uploaded sensor data with the timestamp in tables in *MySQL* database. Client side implementation is done using popular web technologies of HTML(Hypertext Markup Language), JavaScript, and CSS (Cascade Style Sheet). The web page provides real time sensor data visualisation with other useful information, sensor logs, historical data plots, and many more. The web page developed is shown in figure 13

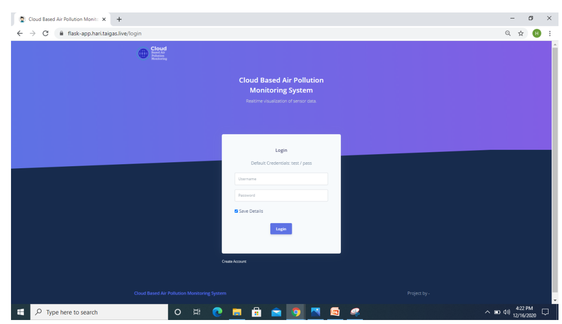

Fig. 13: Login page of web page

IV. Measurements of Pollutants and Comparison

The sensor node which is designed as an array sensor unit comprising of 11 sensors to detect the parameters of air pollution as prescribed by the Central Pollution Control Board (CPCB) is placed in a semi urban area. An Arduino sketch is developed and uploaded in nodeMCU to read the sensor values and then to convert them into gas concentration units such as $\mu gm/\mathrm{m}^3$, parts per million (ppm), or parts per billion (ppb). The sensor data is uploaded in JSON format through the ESP8266 Wi-Fi module and is published to the MQTT broker in the cloud server. JSON format which is a lightweight data format and is suitable to handle sensor data in IoT applications. Arduino sketch is written in such a way to acquire sensor data within every 10 minutes.

Figure 14 shows the COM screen display of uploading sensor data from the sensor node by establishing the MQTT connection with the broker installed in the cloud server.

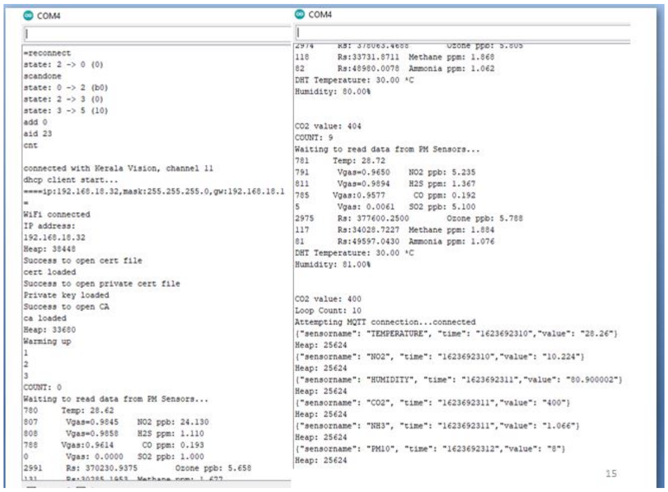

Fig. 14: COM screen display showing sensor data uploading

An instance created in the server acts as the MQTT client which subscribes the sensor data from the MQTT broker which was published from the sensor node in a specified topic and can be viewed on the dashboard of the web page developed. The time-series data subscribed in JSON format is extracted and stored in a database with sensor names and time stamps. The acquired sensor data of pollutants are converted into standard units of gas concentrations as prescribed by pollution control agencies ($\mu gm/\mathrm{m}^3$, ppm or ppb) before uploading and can be visualised on the dashboard with the timestamp and other useful information. The dashboard display is shown in figure 15

By using the time series data from the database, historical data plots are drawn for the past 24 hours by taking the hourly average values of sensor data. The temperature/ humidity plot is shown in figure 16. Along the x-axis is the past time in hours and along the y-axis humidity is in percentage and temperature value in $^{\circ}c$

Hourly average value plot for the past 24 hours for particulate matter (PM1.0, PM2.5, PM10) is shown in figure 17. ”Plantower PMS5003” is the particulate matter sensor used in the sensor array which provides calibrated PM1.0, PM2.5, and PM10 values in $\mu gm/\mathrm{m}^3$

The concentration of pollutant gases from various gas sensors can be visualised in two separate plots. The plot in figure 18 shows the hourly average value for the past 24 hours for the gases CO_2, CO, and CH_4 in ppm (parts per million).

The gas concentrations from the sensors of SO_2, H_2S, NO_2, NH_3, and O_3 are in ppb (parts per billion). The 24 hour data plots for these parameters are shown in figure 19 and the plot is drawn by taking the hourly average value from the acquired sensor data.

30 days historical data plots are created by calculating the daily (24hour) average value for each sensor and these plots are shown from figure 20 to figure 23

Air quality index(AQI) is calculated as per the guidelines issued by The central pollution control board of India and the current AQI value is calculated and displayed in the dashboard of the web page. Using historical data, the past 30 days AQI plot is created and is shown in figure 24. The AQI level is represented by colour bars. The Government of India has issued a standard colour code to report AQI levels and also set criteria to describe the AQI levels as good, satisfactory, moderately polluted, poor, and severe. Increasing the value of AQI means greater the value of air pollution. The Indian AQI colour code chart is shown in figure 25

A. Calculation of AQI

The term AQI (Air Quality Index) is used by government and government approved agencies to intimate the people how much the air is polluted currently or how polluted it is the figure to turn into. The criteria for calculating AQI varies from country to country.

In India, National Air Quality Index(AQI) was established in 2015 under the mission *swachh Bharat Abhiyan*. Central pollution control board(CPCB) and state pollution control boards(SPCB) jointly have been operating NAMP(National Air Monitoring Program). Presently there are 342 monitoring stations(CAAQMS) covering around 240 cities. The new index system measures 8 parameters(earlier it was only three parameters) such as PM10, PM 2.5, NO_2, SO_2, CO, O_3, NH_3, and Pb [37] whereas US AQI is based on 5 criteria pollutants such as ground level ozone (O_3), PM2.5, CO, SO_2, and NO_2. National ambient air quality standards prescribe up to 24 hours averaging periods of the pollutants. This averaging period is 8 hours for CO, and O_3, 24 hours for other pollutants.

The steps for calculating Indian equity is as follows

1. The sub indices for each pollutant from a monitoring station are calculated taking its 24 hours/8 hours average concentration value and health break point concentration range.

2.The sub index(Ip) for a given pollutants concentration (Cp) as based on *linear segment principle* is calculated as

$$I_p = \left(\frac{I_Hi - I_Lo}{B_Hi - B_Lo}\right)(C_P - B_Lo) + I_Lo \qquad (4)$$

where
$B_Hi = Breakpointconcentrationgreaterthanorequaltogivenconcentr$
$B_Lo = Breakpointconcentrationsmallerorequaltogivenconcentratio$
$I_Hi = AQIvaluecorrespondingtoB_Hi$
$I_Lo = AQIvaluecorrespondingtoB_Lo$

3.Finally AQI = Max(Ip) (where,p= 1,2,.....n; denotes n pollutants)

This is illustrated in figure 26

1) Sensor Calibration: Calibration is the process of matching the sensor’s output to a known standard. A Single point or zero point calibration procedure has been carried out for calibrating the gas sensors. This method was adopted because of the lack of availability of controlled environment and equipment to use other methods. The Zero point calibration requires zero air which means clean air. That is air conditioning approximately 78 % nitrogen, 20.9% oxygen, 0.9% Argon and 400 ppm of carbon dioxide(CO_2). All other gases should

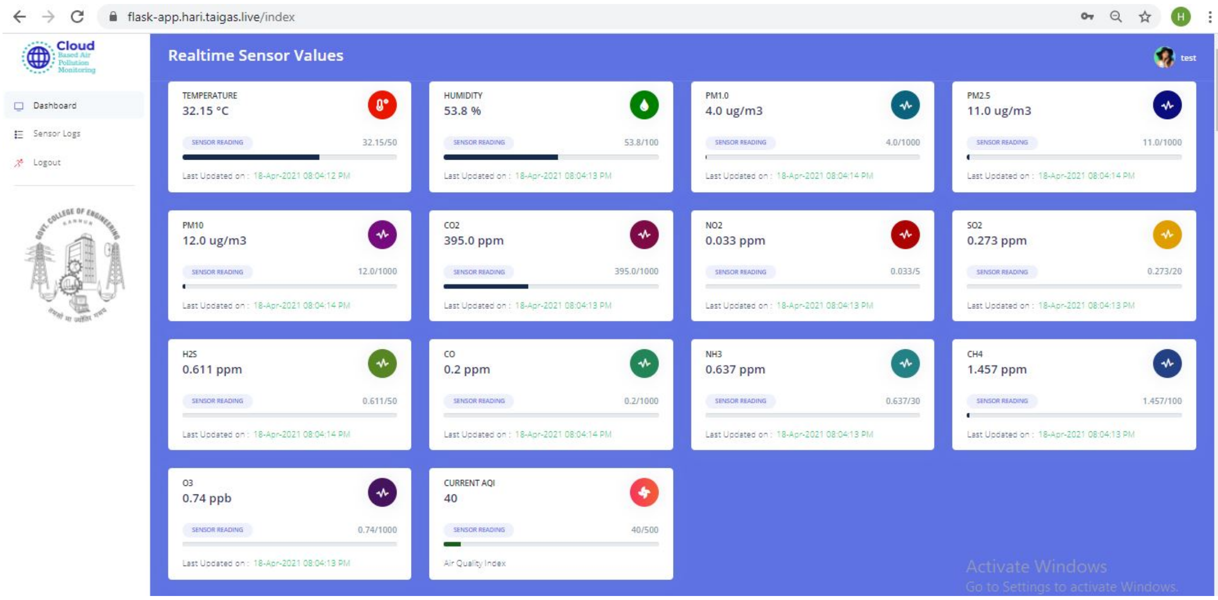

Fig. 15: Dashboard for real time sensor data visualisation

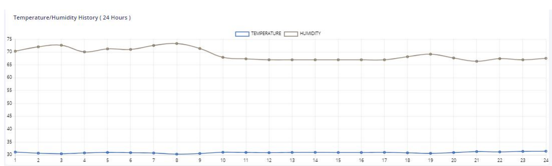

Fig. 16: 24hour data plot of Temperature/Humidity

Fig. 17: 24hour data plot of PM1.0, PM2.5, PM10

Fig. 18: 24hour data plot of gases concentration in ppm

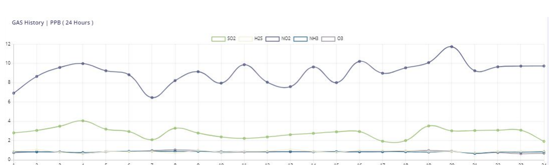

Fig. 19: 24hour data plot of concentration of gases in ppb

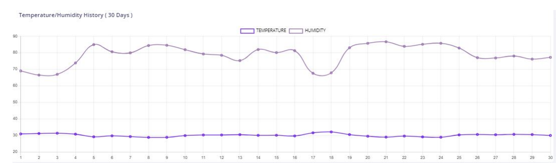

Fig. 20: 30 days data plot of Temperature/Humidity

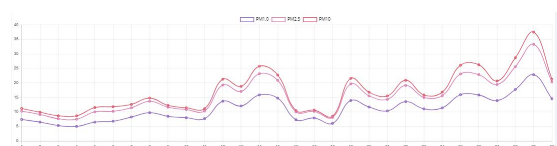

Fig. 21: 30 days data plot of PM1.0, PM2.5, PM10

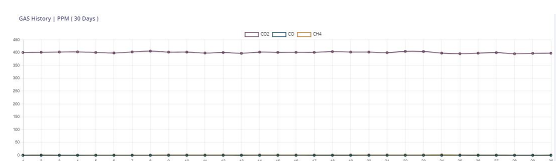

Fig. 22: 30data plot of concentration of gases in ppm

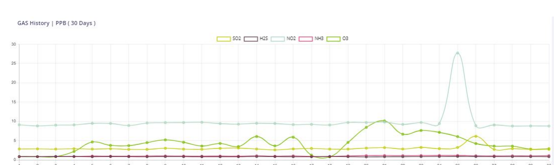

Fig. 23: 30 data plot of concentration of gases in ppb

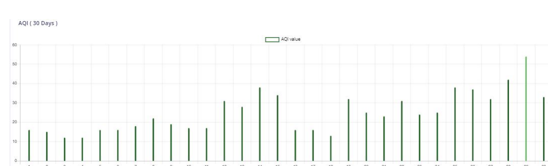

Fig. 24: 30 days AQI plot

AQI	Remark	Colour Code	Possible Health Impacts
0-50	Good		Minimal impact
51-100	Satisfactory		Minor breathing discomfort to sensitive people
101-200	Moderate		Breathing discomfort to the people with lungs, asthma and heart diseases
201-300	Poor		Breathing discomfort to most people on prolonged exposure
301-400	Very Poor		Respiratory illness on prolonged exposure
401-500	Severe		Affects healthy people and seriously impacts those with existing diseases

Fig. 25: Indian AQI Colour chart

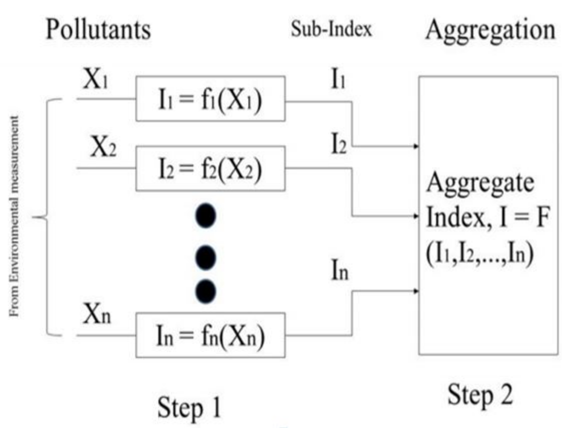

Fig. 26: AQI Calculation

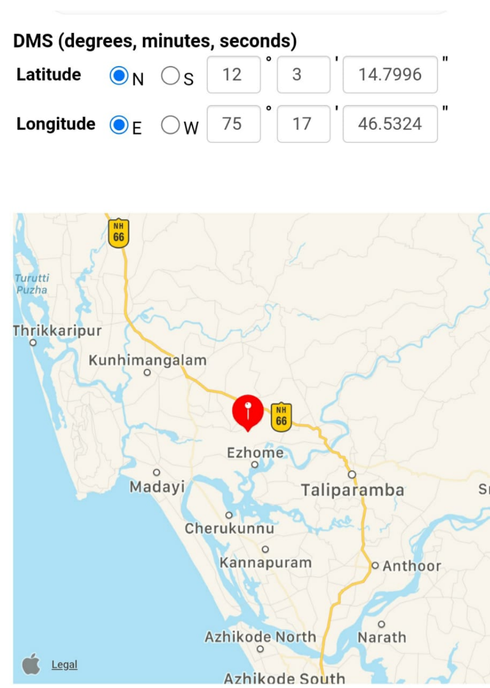

Fig. 27: Location Map of deployment of Array sensor node

be in negligible concentration. However, there is no known standard that defines zero air, the zero readings are taken by exposing the sensors at different places identified where less chance of pollution and with no air transportation. This method is suitable in cases of air pollution monitoring systems where maximum accuracy is less important than total cost.

B. Result Analysis

The indigenously developed *Cloud based air pollution monitoring system* is placed in a semi urban residential area. The location map is shown in figure 27

30 days data of 24 hour average value of pollutant concentration at this location is continuously observed. The observation period is from 16 May 2021 to 14 June 2021 The season is rainy and Covid 19 lockdown period. Average Humidity is 75% and the average temperature is 29°C.Table II shows the minimum and maximum values of the 12 parameters (24 hour average)during this period. The data in the third column shows the maximum permitted value of pollutants in industrial/residential areas as per the guidelines of the Central Pollution Control Board of India.

Table III shows another comparison between the sensor data of the proposed system at the above location and the CAAQMS data of the monitoring station at District Head Quarters, Kannur. This comparison is done on May 15 2021 at 2.45PM.

From this comparison, it is found that the air quality of the current location is better than that of Kannur.

TABLE II: Comparison of 30 days data

Parameter	Minimum	Maximum	CPCB Maximum
PM1.0	$6\mu gm/\mathrm{m}^3$	$23\mu gm/\mathrm{m}^3$	Not specified
PM2.5	$8\ \mu gm/\mathrm{m}^3$	$34\ \mu gm/\mathrm{m}^3$	$60\ \mu gm/\mathrm{m}^3$
PM10	$9\ \mu gm/\mathrm{m}^3$	$38\ \mu gm/\mathrm{m}^3$	$100\ \mu gm/\mathrm{m}^3$
CO_2	392ppm	412ppm	Not specified
CO	0.19ppm	0.202ppm	1.746ppm
CH_4	1.51ppm	2.2ppm	not specified
O_3	2.17ppb	10ppb	43ppb
H_2S	0.8ppb	0.9ppb	Not specified
SO_2	2.5ppb	3ppb	31ppb
NH_3	0.9ppb	1.16ppb	574ppb
NO_2	8.5ppb	10ppb	43ppb
AQI	13	55	500

TABLE III: Comparison of pollutants at current location with CAAQMS data at District Head Quarter

Name of Pollutant	Proposed System	CAAQMS Kannur
PM2.5	$5\mu gm/\mathrm{m}^3$	$29\ \mu gm/\mathrm{m}^3$
PM10	$6\ \mu gm/\mathrm{m}^3$	$31\ \mu gm/\mathrm{m}^3$
NO_2	9ppb	12ppb
CO	0.2ppm	0.34ppm
O_3	1ppb	4ppb
SO_2	1.5ppb	1ppb
AQI	16(good)	48(good)

V. Conclusion

Air pollution is a major problem for human life and our ecosystem. Air Pollution has been increasing day by day due to rapid growth in industries and automobiles. Chemical industries and automobile industries are major sources of air pollution. Various measures are being taken with the help of technological developments to lower the level of air pollution from various sources and protect our environment and human life from dangerous gases emitted from such areas.

An air pollution monitoring system is developed on an efficient Cloud based IoT Embedded Network which helps us to detect and monitor pollution levels in the air in a selected area. This system is built around IoT- cloud computing environment with indigenously developed Array sensor node using low cost sensors that can detect air pollution levels in a local area. The information delivered through a web application shows air pollution levels for the specified area using real time data from sensors. Historical data from sensor logs and historical data plots help us for further analysis and prediction of air quality related factors. This proposed system incorporates minimum hardware such as low cost, low power sensors, communication devices, and a cloud server. Hence this air pollution monitoring system implementation is cost effective as well as energy efficient. Field level sensor calibration using standard calibrating equipment will provide more accurate results.

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