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Original Article

Air Quality Monitor using Arduino

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Abstract *- Indoor Air Quality (IAQ), of late, has been an increasing cause for concern due to its worrisome effects on human health. Indoor surroundings undoubtedly contain pollutants, and their presence has only increased in recent decades due to factors like constructions, furnishings, cooking fuels, personal care products, pesticides, household cleaners, and more. Multiple studies have shown time and again that we humans spend a large amount of our time indoors. Even more concerning is the fact that the ongoing COVID-19 pandemic is forcing us to stay indoors for longer than ever before. This calls for an analysis of our indoor surroundings, the silent pollutants present within, and their corresponding effects on our health.*

With this research work, we present an efficient, low cost and user-friendly indoor air quality monitor developed with an IoT-based sensor network coupled with the Arduino Uno. The resulting system can sense the presence of taint gases like CO, CO2, CH4, SO2, Acetone, and NH3. Sensor data is sent to the cloud, logged, and exposed to the user through interactive graphs. Alerts are provided over email to let the user know in case the optimal threshold for any of these gases is breached.

Keywords *- Air quality Monitor, Arduino, Internet of Things Sensors.*

I. INTRODUCTION

A study conducted by the U.S. Environmental Protection Agency showed that Americans, on average, spend approximately 90 percent of their time indoors. Other studies have mentioned that about 60 percent of a regular organizational workforce works out of an office. It is hence imperative to understand our indoor surroundings where we spend the maximum time of our lives.

Most people don't realize that the air they breathe indoors can be as hazardous or sometimes even more than the air outdoors. Indoor air quality, of late, has become a pressing issue for organizations and governments and has even prompted them to issue safe pollutant levels and guidelines. For example, the Japanese Ministry of Health, Labour, and Welfare had introduced indoor air guidelines for a range of VOCs, including HCHO, based on hazard assessments (Shinohara et al., 2009). Many countries have devoted large amounts of money and Human Resources to the investigation of indoor air contaminants and the methods to control them.

A. Source of Indoor Air Pollution

The sources of indoor air pollution include Radon, NOx, etc., but this discussion is restricted to the gases that are detected by the MQ-7 and MQ-135 sensors. They are listed below

a) Carbon Monoxide (CO)

Gas stoves, generators, and paraffin heaters can be a major source of CO indoors. This gas can also seep in from the outdoor environment and get trapped inside. The buildup of CO beyond safe levels can cause carbon monoxide poisoning, where the body replaces oxygen in the red blood cells with CO. This can result in serious tissue damage and, in some cases, even death.

b) Carbon Dioxide (CO2)

It is a greenhouse gas produced by the air we exhale. It builds up in indoor environments because of outdoor CO2, exhalation, and poor ventilation systems that recirculate contaminated air instead of cycling new air. It can cause restlessness, drowsiness, headache, increased heart rate or blood pressure, and sweating.

c) Ammonia (NH3)

Ammonia is a corrosive, colorless, and pungent gas. It finds its way indoors through construction materials, refrigeration, and cleaning units. Exposure to high concentrations of NH3 through inhalation can cause respiratory irritation and burning of the nose, throat, or respiratory tract.

d) Hydrogen (H2)

It is a colorless, odorless and flammable gas. When exposed to it in high concentrations through inhalation, it can cause unconsciousness, headaches, dizziness, nausea, vomiting, and ringing in the ears. The victim's skin may turn blue.

e) Methane (CH4)

CH4 is a colorless, odorless, and flammable greenhouse gas. It is used for cooking and heating in homes and is the primary component of bio/natural gas. Exposure to high concentrations of CH4 can cause headaches, slurred speech, vomiting, nausea, vision problems, and memory loss.

f) Volatile Organic Compounds (VOCs)Volatile

Organic Compounds or VOCs are carbon-containing gases or chemicals present within indoor environments. Most of these VOCs have higher concentrations indoors

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than outdoors. They are commonly found in paints, waxes, varnishes, polishes, disinfectants, cleaners, and other household products. These products can release VOCs when they are being used or stored. Their health effects include eye, nose, and throat irritation, headache, nausea, loss of coordination, fatigue, dizziness, and in adverse cases, some of them are known to be carcinogenic.

B. Our Project

This project is the result of the research conducted with respect to the implications of IAQ, as stated above. The main aim of the project is to provide real-time, cost-effective indoor air quality monitoring that is suited to households and small offices. It includes two sensors, namely the MQ-2 and MQ-135 sensors, to detect the gases mentioned above and provide readings to an Arduino Uno. The Arduino Uno reads the analog values from the sensors and post-conversion, relays the same over WiFi using an ESP32 WiFi module to the Python-FastAPI back end. The back end parses the data and makes data available for an interactive front end written in Vue.js to provide real-time visualization of indoor air quality. As an added advantage, email alerts are sent to the user in case the safe thresholds of any of these gases are breached.

II. LITERATURE SURVEY

The paper's vision in [1] to develop a cost-effective IoT air monitoring system aligns with our aims as well. An air sensor (MQ5) has been used to detect the presence of harmful gases/compounds, which are continuously transmitted to a controller (Raspberry Pi). The controller then processes this data and transmits it via the internet. Noise sensing and soil moisture sensing are also incorporated to provide all-around pollution monitoring capability. Alerts are provided via a Twitter Bot. Data is logged in a MySQL database and is exposed to the user via graphs on the ThingSpeak platform.

[2] discusses a design of an IAQ system using the ESP32 as a controller and several sensors to measure air quality. Indoor air quality standards and parameters have been determined by the Decree of the Minister of Health of the Republic of Indonesia Number 1405 of 2002 concerning Requirements and Procedures for Health Implementation in Office Work Environment as humidity, dust particles, and pollutant gases such as Hydrogen Sulfide (H2S), Ammonia (NH3), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), and Sulfur Dioxide (SO2). The various components used are ESP32 (development board), BME280 sensor module (to sense humidity and pressure), GP2Y1010AU sensor (to sense dust), MQ-136 sensor (to sense H2S), MICS-6814 sensor (to sense NH3, CO, NO2), and Winsen ZE03-SO2 sensor (to sense SO2). The sensed data is displayed using an LCD screen and is pushed to the ThingSpeak Cloud.

[3] presents a thorough analysis of the analysis of sources and the adverse health effects of several common indoor air pollutants. Chemical pollutants, which often come from cooking, cleaning, smoking, construction materials, and biological pollutants, such as allergens produced by dust mites, pets, and molds, including the Volatile Organic Compounds (VOCs) and toxins released by these moulds, are stated to be the major contributors to indoor pollution. The health impact of formaldehyde, nitrogen dioxide, VOCs, radon, particulate matter, and biological pollutants are outlined in great detail. Additionally, methods to improve air quality are suggested. Some of them are source control, improvement of air conditioning ventilation, and air cleaning.

The project developed in [4], after addressing the common air pollutants, proposes a prototype for a low-cost indoor air monitoring device that measures the concentration of CO and HCHO gases while communicating data over the cloud to notify any wireless device when the threshold of these gases is reached. The components consist of a Marvell EZ Connect SoC board, Grove sensors, and a mobile device to test incoming notifications. The Marvell AWS Starter SDK is utilized to establish a bidirectional connection to the AWS cloud and interface to the various IoT-related services offered by AWS. The advantages of such a device in schools, factories, and homes are analyzed thoroughly.

[5] presents a comparison of the air quality in different areas of Dhaka City before and after the COVID-19 pandemic by tracking the concentration of gases like carbon monoxide and nitrogen dioxide. The product consists of a Node MCU board paired with an MQ-135 gas sensor and an MQ-7 gas sensor at the perception layer, the node MCU's wireless module at the network layer, MS Excel to visualize data at the application layer, and Firebase for data persistence. Sensor data was interfaced with code using the Arduino IDE. Statistical analysis like moving average, correlation coefficient, standard deviation, and frequency distribution is performed on raw data to smooth out the noise of random outliers. The project concludes that the concentration of nitrogen dioxide had marginally decreased after the lockdown, but the concentration of carbon monoxide had increased.

[6] aims to help make the smart city initiative of the various states of the world successful by proposing a cost-effective solution for monitoring air quality using the LoRa Wide area network and sensors. Studies show that a person breathes in approximately 11 Kilo Litre of air every day, and inhaling harmful pollutants may have long-term health effects. The IOT system has the sensing layer or perception layer which senses and measures the data from sensors like RFID nodes etc., and the network layer uses HTTP or Bluetooth, 3G, 4G, or Low Power Wide Area Network to transmit the data received from the sensing layer to cloud server and the last is Application layer which acts as an interface between the application and end-users like a mobile application. So, the sensed data is received by the LoRaWAN gateway, which is a type of LPWAN, it is stored in the InfluxDB database, which is sent to Grafana servers, and a graphical dashboard is made available to the users. Also, the Auto-Regressive

Integrated moving average(ARIMA) model is applied to the DB data, and predictions of parameters are made, which helps in taking precautions.

[7] discusses a design of a system that small-scale industries can use for monitoring humidity, temperature, pollution through wireless devices. Wireless Sensor Nodes(WSNs) are built of nodes placed in a network, and each node is connected to one or several sensors. There are many harmful gases that are emitted from an industry like Helium, Chlorofluorocarbon, Carbon dioxide, Nitrous Oxide, etc., and these are very harmful to the workers and people living nearby. All these numerous gases were taken into consideration for dashboard visualization. Raspberry Pi, along with ZigBee and programming language C.Net, was used as an IOT gateway; the data was sensed, stored in SQL database, and sent to a web-server for visualization in VB.Net. This is an efficient and cost-effective way.

[8] proposes a cost-effective and accurate measure of temperature, earthquake, humidity, light level, air quality using Raspberry Pi, which is a low-cost, Linux-based computer, the size of a credit card, the general-purpose Input-output has 26 pins. There are two main parts, one is designing the sensor parameters, and the other is using Raspberry Pi for monitoring and interpretation. Then the sensors are all connected to the Raspberry Pi, some libraries like pip, python-dev, python-SMBus, Raspberry Pi.GPIO is used, and Xively is used as it offers an IOT platform that helps connect products and businesses to the worldwide network. The data sent are sent to Xively, which displays it in an interactive dashboard.

[9] discusses the harmful effects of air pollution and hence the necessity for an air quality monitor. Air pollution is caused by natural calamities like volcanoes, typhoons, forest fires, etc., as well as human activities like the burning of fossil fuels, vehicles, industries, coal, consumption of electronics, etc. Air pollution is caused by any pollutant or substance which, when it reaches above a certain concentration in the environment, causes harm to all living beings on the planet. Different pollutant categories are heavy metals, gaseous pollutants like ozone, SO_2, etc., organic pollutants, and particulate matters; when any of these pollutants come into contact with living organisms by air, water, or soil, it results in deterioration and harmful effects on the cardiovascular, respiratory, digestive, nervous system and urinary system.

[10] implements a system that monitors data received from sensors like air quality, humidity, temperature and can be used for assisting patients who might have a history with lungs related problems. This paper uses ZigBee to monitor the quality of air and in a Ubiquitous Ambient Assisted Living Environment. As people spend a lot of time indoors, i.e., in offices, schools, colleges, dormitories, it is very important to have proper air quality, and it is all the way more crucial that people with the respiratory illness have a system to monitor air quality. This is a system where data is captured through sensors, and an IOT gateway is used to send the sensed data to the ScadaBR, which is a supervision system that also stores the data in a database. This data can be accessed by third-party vendors or caretakers to enable them to provide care to their patients.

With increasing levels of pollution in air and noise, the paper in [11] proposes a design to build a device to monitor Air Quality Index and Noise Pollution levels in a region.

They have taken the LM393 sound sensor, MQ135 gas sensor, DHT11 temperature and humidity sensor, and Raspberry Pi 3B for the implementation.

LM393 sound sensor - Detects sound, processes output signal voltage and sends the same to the RaspberryPi, MQ135 gas sensor - Detects levels of NH_3, NO_x, smoke, and CO_2 in the atmosphere, DHT11 temperature, and humidity sensor - Used to monitor humidity and temperature levels and Raspberry Pi 3B - Single board computer used to collect data from the sensors and process it. GPRS module to connect the raspberry pi to the internet using mobile data.

[12] addresses the incessant levels of air pollution by proposing to design a system consisting of DSM501A, which is a Particulate Matter sensor along with sensors to detect carbon monoxide carbon dioxide, temperature, humidity, and pressure levels. The proposed system provides a low cost, low power, compact, and highly accurate system for monitoring the environment with dedicated sensors remotely from any place in this world. The proposed objectives are achieved in this paper.

[13] analyses indoor air quality and its effects on the health of human beings. The impacts due to combustion by cooking, smoking, and heating. Furthermore, this paper also reviews the effects of other factors such as asbestos and volatile organic compounds (VOCs). The article discusses gases like CO, CO_2, NO and their effects, as well as biological sources such as allergens, and reviews their effects on the health of a human.

[14] proposes to design a measurement system that can measure particulate matter smaller than 10 and 2.5 microns and measure four hazardous gasses, including carbon monoxide, Sulphur dioxide, ground-level ozone, and nitrogen dioxide. The paper has successfully satisfied its objectives with respect to designing a new measurement system.

[15] proposes a design and develops a method to measure the levels of CO and CO_2 using an MQ-7 sensor and an MQ-135 air quality sensor which is connected to a microcontroller. The values of CO and CO_2 are calculated in parts per million and displayed.

III. METHODOLOGY

The overall structure and flow of our project are mentioned henceforth. First, the system is powered on using a portable power supply which in our case is a power bank. Then, the sensors get powered on by the Arduino's voltage pins, and they are calibrated using Arduino code. Once the sensors are initialized, they detect gases in the environment and provide their readings through analog signals, which are read on the analog pins of the Arduino. The raw sensor readings are converted to usable ppm readings of individual gases using Arduino code once again. Using a different function, this converted data is sent to the back-end API using a POST request. Data is pushed every 10 seconds to nullify false-positive triggers from the sensor and improve accuracy. The back-end API stores this data in the database. A front-end dashboard makes a request in sync with the pushed data to retrieve the last fifteen logged values and then displays them in real-time, interactively. In case the back end is not reachable, apt error messages are displayed to the user.
This entire flow is shown diagrammatically in the form of a flowchart below.

Fig. 1 High-level design of air quality monitor

A. Low-Level Design – Sensor Data Reading and Conversion

- The MQ sensors work on the basis of semiconductors. Once they are powered on, they provide indoor air quality measurements with reliable accuracy for household use cases.
- The Arduino powers the sensors using its 5V pins and reads the analog signals coming from the sensor using its analog pins. The Arduino is powered by an external power source which, in this case, conveniently, is a USB power bank.
- Arduino can interact with sensors using its code from the Arduino IDE.
- The code consists of methods to calibrate the sensors and read their values. The read values should necessarily be converted to ppm of individual gases. This is done with the help of the log readings from the chart given by the MQ sensor manufacturer. Different gases like CO, CH_4, H_2, etc., have different slopes on this chart, and when the required values are plugged into the formula, the ppm values are obtained.
- Once all of the code for the above is written within the Arduino IDE, it is compiled and uploaded to the Arduino, which runs it in a loop.
- Sensor readings are taken every 10 seconds to reduce the chance of false positives and clogging the database with redundant values.
- The ESP-01 WiFi module is wired to the Arduino, and this provides it with WiFi connectivity and Serial communication capability. Another method is written within the Arduino IDE to make a POST request to a back-end REST API endpoint. A request is made when sensor data is received, i.e., every 10 seconds.
- This process continues for as long as the Arduino is powered on.

B. Low-Level Design- Backend

The back end is written in Python using a new framework called FastAPI. This framework works best for asynchronous REST APIs. The back end connects to an SQLite3 database using an ORM called SQLAlchemy. When data is received on its endpoint through a POST request, a method first parses this data and identifies the gases that have breached the safe thresholds. In case there are such gases, the environment could be harmful. To alert the user of this information, the smtplib module is used to send an e-mail alert using Gmail servers to the user. This occurs as and when data is received from the sensors, i.e., every 10 seconds. So the alerts are assured to be real-time with minimal latency. Once the e-mail is sent, the data is logged to the database using an ORM method. This provides data persistence. The other endpoints are open to GET requests to supply sensor data values that are logged in the DB so that the front end can use them.

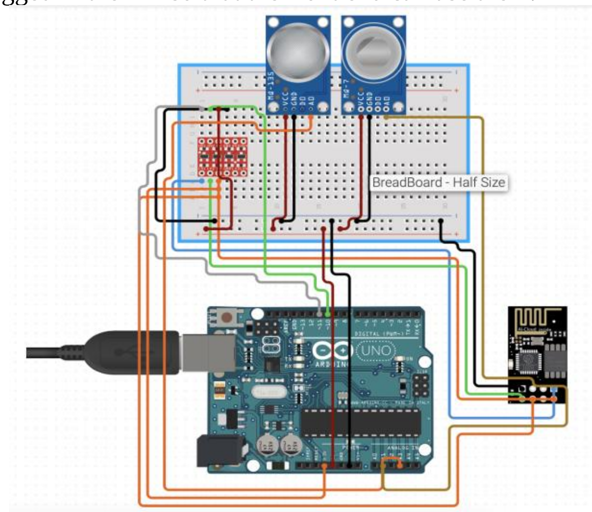

Fig. 2 Circuit diagram of air quality monitor

C. Low-level design- Frontend

Ad The front end is written in JavaScript using a framework called Vue.js. Once the DOM is initialized, a request is made to the REST API endpoint to get the last 15 values from the database. These values are parsed and rendered as a chart using a module called chart.js. Chart.js also provides the functionality to filter based on the value groups on the y-axis. The necessary colors are applied to each gas for distinction, and the legend is created on top for visibility. The request made above is made in sync with Arduino's request, i.e., every 10 seconds to get the latest values and provide real-time monitoring.

IV. RESULTS

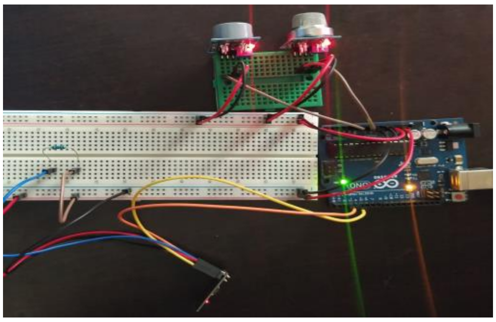

Fig. 3 Arduino Setup of Air Quality

Fig 3 shows us the Arduino setup done by us for the execution of the project.

On running our models, we get the following dashboard.

Fig. 4 Final Dashboard of Air Quality Monitor

The dashboard in fig 4 has different colors depicting the different gases being measured by the Arduino. The moment a particular gas crosses the safety threshold, an email alert is sent to the user.

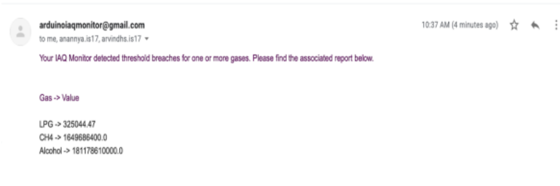

Fig. 5 Email alert with details of gases breached the threshold

V. CONCLUSION

We set out to do this project and its associated research with the aim of providing an efficient, low cost and real-time indoor air quality monitor that is suited to homes and small offices. The implementation of it achieves this objective. The system costs less than Rs. 1000 and the associated code is open source. A user can monitor his or her indoor environment in real-time, interactively, and receive alerts in case the safe thresholds of these gases are exceeded.

All the important deliverables were realized, and the work was in line with the scope defined at the beginning of the project. The shortfalls were also noted, and they shall be addressed in the next iteration.

The team gained experience in the field of IoT and harmful chemicals in an indoor environment. On the technical side, the team worked with and understood the implementation of Arduino IDE/code to read sensor data as well as relevant frameworks and technologies for popular languages like Python and JavaScript.

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