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AIR QUALITY MONITORING SYSTEM

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Abstract: The alarming rate at which air quality has been degrading over the past few decades causes about seven million deaths worldwide each year. Transparency regarding the standard of the environment that people across the world live in is necessary in order to make the right decisions before it is too late. National Ambient Air Quality Standards (NAAQS) for six major pollutants that can be hazardous to the environment and public health have been established by the United States Environmental Protection Agency (USEPA). The National Air Quality Monitoring Program (NAMP), run by India's Central Pollution Control Board (CPCB), is a nationwide program for measuring ambient air quality. Governmental organisations are in charge of informing the populace about health risks and how to prevent them. The idea suggests an air quality monitoring system that figures out how much of certain dangerous gases are present in the atmosphere. The Raspberry Pi Pico W and Arduino UNO are used to collect and process data from the gas sensors monitoring carbon monoxide and ammonia. The sensor data is categorised into groups depending on concentration and their level of health impact, and an AQI (Air Quality Index) is computed. The classification is carried out in accordance with the CPCB's instructions. Cloud storage is used to upload the data for remote monitoring. When pollution levels are too high, an audio alert is produced using AQI data.

***Index Terms* - Outdoor Air Pollution, Air Quality Index, Public Health, Wi-Fi**

I. INTRODUCTION

For tracking the development of a sustainable, just, and healthy future, air pollution is a crucial indicator. The success of policies and initiatives for sustainable energy (such as energy access, energy efficiency), sustainable consumption, urban growth, climate change, and infrastructure is directly reflected in improvements in air quality. In addition, air pollution exposure is a major source of mortality and morbidity around the world, making data on air pollution levels and their spatial and temporal patterns a crucial and practical indication of the health effects of sustainable development. Air pollution is the biggest environmental threat to sustainability, climate change, and human health. Outdoor and indoor air pollution cause around 7 million premature deaths each year, making air pollution one of the leading causes of premature mortality and morbidity globally. Inefficient energy generation, usage, and distribution of energy services, as well as inefficient industry, transportation, and housing, as well as solid waste management systems, are key drivers of air pollution emissions. A monitoring system is essential to keep the public informed about environmental conditions. It is beneficial to persons who have illnesses that are worsened or caused by air pollution. As a result, it enables individuals to change their regular activities when they are alerted of excessive pollution levels. This can also assist organisations execute air pollution management initiatives. In the study carbon monoxide (CO) and ammonia (NH_3) emissions in the surrounding environment are monitored using gas sensors. The data gathered is transferred to the ThingSpeak cloud platform. The Air Quality Index (AQI) is calculated using the gathered data, and an audible alert is issued when pollution levels exceed the healthy range.

II. Literature Review

Air pollution in major cities has a devastating impact on both individuals and the environment. The number of environmental challenges in India is rapidly increasing. Vehicles and industry are the primary sources of air pollution, which causes a variety of respiratory ailments such as asthma and sinusitis. The air quality in major cities such as Kolkata, Delhi, and Mumbai is poor due to high levels of carbon dioxide and other hazardous gases generated by automobiles and factories. An extensive number of projects have been described in the literature that are used to monitor air pollution. The reports of air pollution call for urgent action of the government.

Nidhi Sharma et al. analysed extensive data analysis of air pollutants from 2009 to 2017 and provided a critical observation of the 2016-2017 air pollutants trend in Delhi, India [2]. Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Suspended Particulate Matter (PM), Ozone (O_3), Carbon Monoxide (CO), and Benzene are among the pollutants whose future trends are forecasted. The future levels of the pollutants indicated previously are forecasted using data analytics Time series Regression forecasting based on existing records. The study results at Delhi's AnandVihar and Shadipur monitoring stations revealed a significant rise in PM10 concentration levels, as well as NO_2 and PM2.5 levels, indicating increasing pollution in the city.

Jingchang Huang (et al.2019) introduced Crowdsource Sense [3], a crowdsourced urban air quality detection system in China. The primary theory behind Crowdsource Sense is that the air component concentration in a local urban area is extremely near to that in a car when the windows are open, because air exchanges between the interior and outside of a vehicle. The study was suggested in order to assess the ambient humidity and temperature, as well as the concentrations of PM2.5 and TVOC, two of the most concerning air pollutants in urban environments. Crowdsource Sense first creates an intelligent algorithm to detect vehicle air exchange status, then extracts pollution concentrations, assuming the concentration trend is steady after opening.

S. Dhingra et al. developed an IoT mobile-air pollution detecting app [4]. An air pollution detection kit was created by combining data from gas sensors (carbon monoxide, carbon dioxide, and methane) and Arduino, which read the concentration of gas in the area. An IoT kit was created by connecting an ESP8266 Wi-Fi module to a cloud platform called Ubidots, where the AQI is computed and presented on the web. Using Ubidots services, an Android application was created to monitor sensor data. The programme computed AQI in real time and forecasted daily air quality for a specified city. The suggested system confronts computational difficulty, especially when dealing with large amounts of sensor data. The study suggests using fog computing instead of cloud computing.

Moharana BK et al. [5] present a NodeMCU ESP32-based air quality monitoring system that includes a MQ-135 gas sensor and a DHT-11 temperature and humidity sensor module. The sensors collect data and communicate it to the NodeMCU, which serves as the total setup's base station. The NodeMCU, which has an onboard microcontroller and a Wi-Fi transmitter, not only monitors data but also sends it to a distant server. The gas sensor detects harmful chemicals such as NO_2, CO_2, benzene, and smoke and provides an overall air quality index. If the concentration of dangerous gases surpasses a certain level, a warning message is shown on the server. The technology was tested in two distinct places at NIT Warangal.

The building is outfitted with various sensors that monitor its energy use as well as the internal and exterior surroundings [6]. The authors concentrated solely on sensor applications for monitoring indoor air quality (IAQ) in buildings. Waspmote sensors are employed in the building's IAQ sensor network. The sensor can detect air pollutants such as ammonia, ethanol, hydrogen sulphide, and toluene, as well as carbon monoxide, carbon dioxide, and oxygen in parts per million. Sensor data collected by the Waspmote plug and sense nodes is delivered to the cloud by the Meshlium, a gateway router specifically intended to link Waspmote sensor networks to the Internet through Ethernet, Wi-Fi, and 3G interfaces.

III. ARCHITECTURE

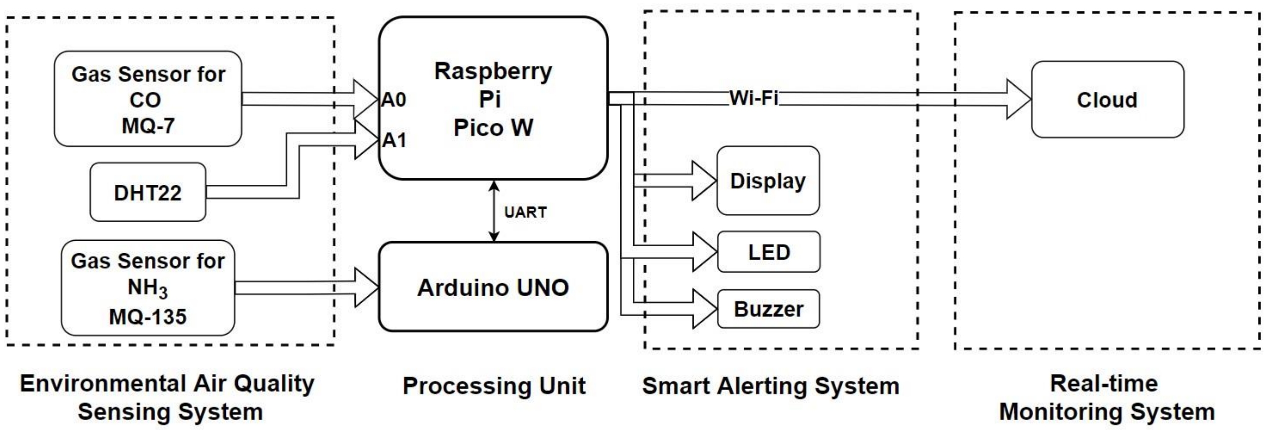


Figure 3.1: Architechture of Air Quality Monitoring System

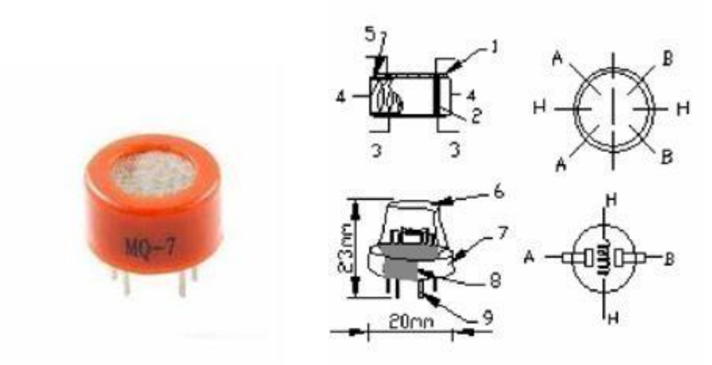
Figure 3.1 shows the architecture of air quality monitoring system. The raw data collected from the sensors measuring the pollutant The block diagram of an AQI monitoring system is shown in Figure 3.1. The raw data acquired from the pollutant concentration sensors is calibrated using a control unit before being transferred to the cloud over Wi-Fi for analysis. The AQI (Air Quality Index) is classified into six levels. Each category represents a distinct level of public health concern. Each group also has its own colour. The colour allows people to immediately identify whether the air quality in their towns has reached dangerous levels. An AQI score of 100 normally equates to an ambient air concentration that equals the level of the short-term national ambient air quality standard for public health protection for each pollutant. AQI scores of 100 or below are typically regarded as good. When AQI values exceed 100, air quality becomes unhealthy: initially for some vulnerable groups of individuals, then for everyone as AQI values rise. When the AQI surpasses a given level, a buzzer sounds. This data may be accessed via the cloud.
Raspberry Pi Pico W is a microcontroller board based on the Raspberry Pi RP2040 microcontroller chip. Raspberry Pi Pico W has been designed to be a low cost yet flexible development platform for RP2040, with a 2.4GHz wireless interface. Thonny Integrated Development Environment (IDE) is used to write firmware for Pico W. The Arduino Uno R3 SMD Board is microcontroller board based on the ATmega328P designed to be used with the Arduino IDE, which provides an easy-to-use programming environment. Arduino board is additional and added for the ease of implementation. MQ-7 and MQ-135 are the gas sensors used to detect CO and NH_3 respectively. DHT22 is used to measure temperature and humidity. ThingSpeak is the IoT cloud platform used to upload real time data.

IV. Implementation

4.1 MQ-7 Gas Sensor

4.1.1 Heat Cycle Requirement and Structure of MQ-7 Gas Sensor

A semiconductor sensor called the MQ-7 (SnO_2) is used to measure CO levels in the environment. To eliminate and reduce the factors that lead to inaccurate results, these semiconductor sensors need calibration. Gas sensor calibration with calibrating apparatus is a more difficult and expensive operation. The paper principally focuses on an easy way to derive a formula to measure CO concentration in particles per million and equipment-free calibration of the MQ-7 semiconductor sensor [7]. Moreover, a method for addressing the sensor's heater cycle need.



	Parts	Materials
1	Gas sensing layer	SnO_2
2	Electrode	Au
3	Electrode line	Pt
4	Heater coil	Ni-Cr alloy
5	Tubular ceramic	Al_2O_3
6	Anti-explosion network	Stainless steel gauze (SUS316 100-mesh)
7	Clamp ring	Copper plating Ni
8	Resin base	Bakelite
9	Tube Pin	Copper plating Ni

Figure 4.1: MQ-7 Sensor Structure

The MQ-7 gas sensor is made up of a nickel-chromium (NiCr) heater coil mounted into a crust made of plastic and stainless-steel net, a measuring electrode, a tin dioxide (SnO_2) sensitive layer, and a micro-Aluminum Oxide (Al_2O_3) ceramic tube. The sensor's construction is shown in Figure 4.1. Typically, the MQ-7 sensor has six pins. You can connect pins A and B independently. The accompanying Table 4.1 [9] contains the MQ-7 gas sensor's specifications SnO_2, which exhibits higher electrical resistance (lower electrical conductivity) in clean air and lower electrical resistance (higher electrical conductivity) when there is a high CO concentration, is the main sensing component of the MQ-7 gas sensor. For inside delicate components, the heating coil provides the required operating environment. As a result, it is necessary to keep up a series of heating cycles in order to measure the CO concentration. As illustrated in Figure 4.2, the heat cycle consists of a high-temperature state and a low-temperature state. In order to measure the CO concentration, a low-temperature state is created by applying 1.4 V across the heater coil for 90 seconds. Additionally, to reach the high-temperature condition, in which additional gases absorbed during the low-temperature state are cleaned, 3.3 V must be supplied across the heater coil for 60 seconds. In order to monitor CO concentration accurately, the heat cycle must be maintained continually. To get stable results, a heat cycle was applied for 10 minutes.

Table 4.1: MQ-7 Gas Sensor Specifications

(a) Standard work conditions

Symbol	Parameter name	Technical condition	Remark
V_C	Circuit voltage	5V ± 0.1	Ac or dc
V_H(H)	Heating voltage (high)	5V ± 0.1	Ac or dc
V_H(L)	Heating voltage (low)	1.4V ± 0.1	Ac or dc
R_L	Load resistance	Can adjust	
R_H	Heating resistance	33Ω ± 5%	Room temperature
T_H(H)	Heating time (high)	60 ± 1 seconds	
T_H(L)	Heating time (low)	90 ± 1 seconds	
PH	Heating consumption	Above 350mW	

(b) Sensitivity characteristics

Parameter name	Technical condition
Standard working condition	Temperature: -20ºC ± 2ºC
	Relative humidity: 65% ± 5%
	RL: 10KΩ ± 5%
	V_C: 5V ± 0.1 V_H: 5V ± 0.1 V_H: 1.4 ± 0.1
Preheat time	No less than 48 hours
Detecting range	20-2000 ppm

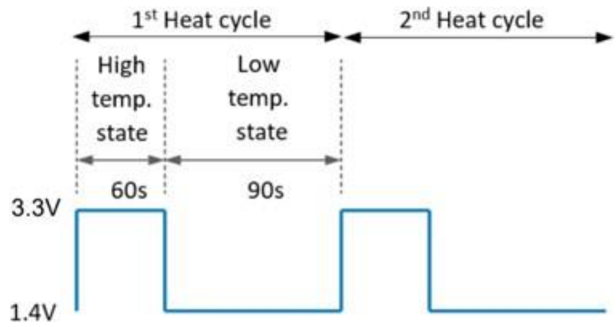


Figure 4.2: Heat cycle with high and low-temperature states

4.1.3 Implementation of Heater Cycle Requirement

Based on the Pulse Width Modulation (PWM) technique of a Raspberry Pi Pico W microcontroller, the heating cycle of the sensor was accomplished. PWM is a technique for getting digital results from analog sources. A square signal, which alternates between being on and off, is produced using digital control (High and Low). This on-off pattern can simulate voltages between the board's full VCC (Voltage Common Collector) and off by changing the portion of the time signal spends on (High) versus the signal's time off (Low). A period is the length of time needed for a signal to complete an on-and-off cycle, and the duty cycle is the percentage of time the signal was high (on) during that period. PWM powers devices in a manner that is similar to the average of the pulses. The duty cycles of the PWM signal were tuned to be equivalent to 3.3 V and 1.4 V in order to satisfy the sensor's heating cycle requirement. The maximum current on a single GPIO pin of a Raspberry Pi Pico W is restricted to 16 mA. The MQ- 7 sensor, however, requires a substantially greater current to run the heater cycle and has a heater consumption of 350mW as shown in Table 4.1, which is often above the specifications of the Raspberry Pi Pico W. To handle the high current needed for the heater coil, a Metal-Oxide Semiconductor Field-Effect Transistor (MOSFET) was employed as the solution. When compared to Bipolar Junction Transistors (BJT), a MOSFET's responsiveness and high current capability were primarily taken into account. An N-channel MOSFET (IRF840) was utilized in the experimental setup to implement the necessary PWM signal to operate the heater coil of the sensor, as shown in Figure 4.3.

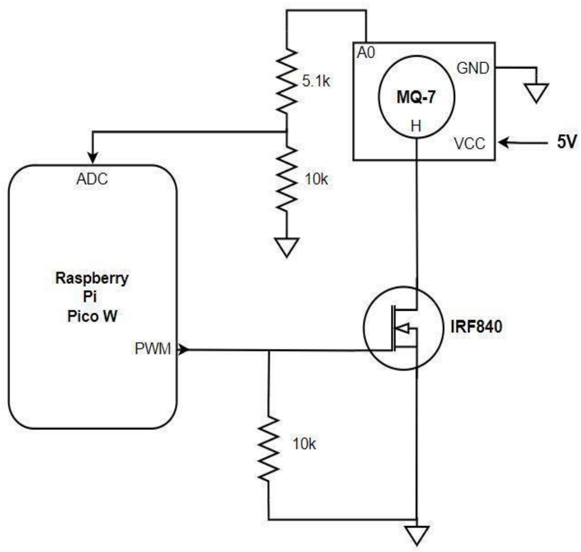


Figure 4.3: Implementation of heater cycle by using Raspberry Pi Pico W

4.1.4 Calibration of MQ-7 Gas Sensor

Figure 4.4 [9] depicts the sensitivity characteristics of the MQ-7 sensor. The graph can be used to calculate the CO concentration in ppm in relation to the resistance ratio (R_S/R_O) of the sensor; the calibration procedure also follows this same idea. The premise that the surrounding air is pure was used to conduct this experiment. The graph's x and y axes have logarithmic scales.

R_O – Gas sensor resistance in clean air

R_S – Gas sensor resistance at different CO concentration

The graph clearly shows that the MQ-7 sensor's resistance ratio (R_S/R_O) in clean air is around 25.75 (refer to the characteristic curve corresponding to air).

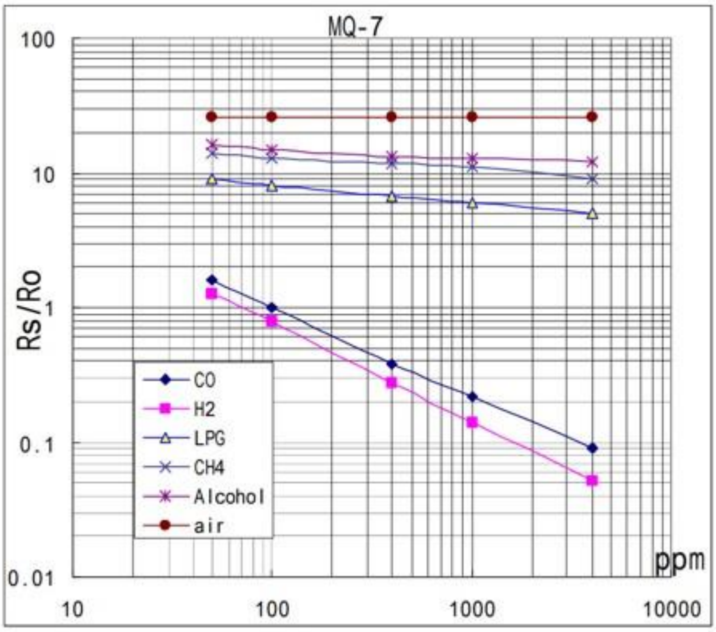


Figure 4.4: Sensitivity characteristics of the MQ-7 sensorAs a result, the resistance ratio in clean air can be expressed as follows.

$$\frac{R_s}{R_o} = 25.75 \qquad (4.1)$$

Since the resistance ratio is already known to be 25.75, the remaining term R_O in Equation 4.1 can be calculated if the value of R_S in the equation is known. As a result, the calibration method seeks to identify R_O in conditions of ambient air (clean air). In light of Equation 4.1, it is necessary to determine the value of R_S in order to calculate R_O. It is necessary to carry out the experimental procedures outlined in the following sections in order to ascertain the value of R_S in clean air. The following expression can be obtained by applying the voltage divider rule to the circuit in the Figure 4.5.

$$V_{RL} = V_C * \left(\frac{R_L}{(R_S + R_L)}\right)$$

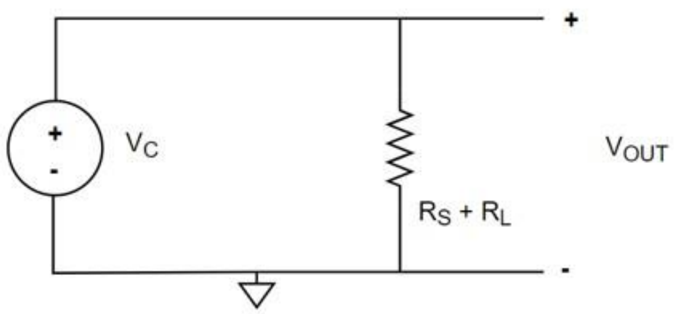


Figure 4.5: Internal Circuit Diagram of MQ-7The sensor resistance R_S can be calculated as

$$R_S = \left(\left(\frac{V_C}{V_{RL}}\right) - 1\right) * R_L \qquad (4.2)$$

Equation 4.2 only has one variable that is unknown, V_{RL}. It is discovered experimentally in the manner outlined below.
A 10kΩ resistor was utilized as the load resistor R_L for the experimental setup, and the Arduino microcontroller was used to measure the voltage V_{RL} across the load resistor.

4.2 Determination of CO Concentration

The experimental setup used to calculate CO concentration is shown in Figure 4.6. Equations 4.1 and 4.2 are implemented in the microcontroller unit to obtain the value of R_O directly from the experimental setup. After the test was finished, the average R_O value was found to be 4.83kΩ. Due to the impacts of temperature and humidity during the experiments, small changes in the data points were seen. These two parameters' combined effects were not considered.

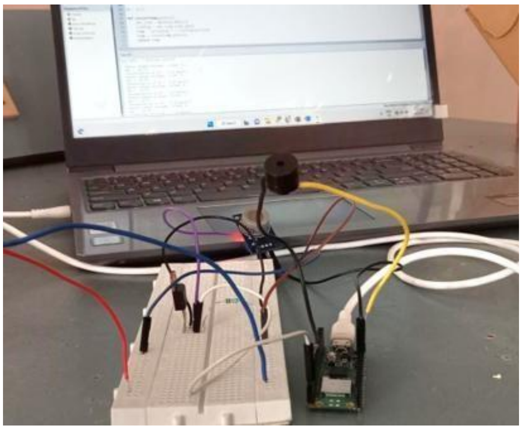


Figure 4.6: Experimental setup for the CO Concentration measurement

The sensor data sheet includes a CO characteristic curve that can be used to calculate CO concentration under any circumstance after the calibration procedure is complete. However, utilizing only the graph to manually calculate the gas concentration corresponding to the resistance ratio is a laborious and time-consuming task. As a result, using a computer program to determine the characteristic curve equation simplifies the procedure and yields more precise results. Extracting the resistance ratio (R_S/R_O) data points and the matching CO concentration values is necessary in order to create an equation. The retrieved data points were utilized to create Table 4.2.

Table 4.2: Data points extracted from the CO characteristics curve using WebPlotDigitizer

CO Concentration(ppm)	Resistance ratio (R_S/R_O)
50.5	1.63
103.8	0.981
198.01	0.615
300.6	0.46
1051.9	0.215
1858.79	0.148
3871.79	0.09

A new graph was created utilizing the data points taken from the CO characteristic curve, as seen in Figure 4.7. The trendline function in Microsoft Excel was then used to find the best fit curve and associated equation, which more accurately depicts the original CO characteristic curve.

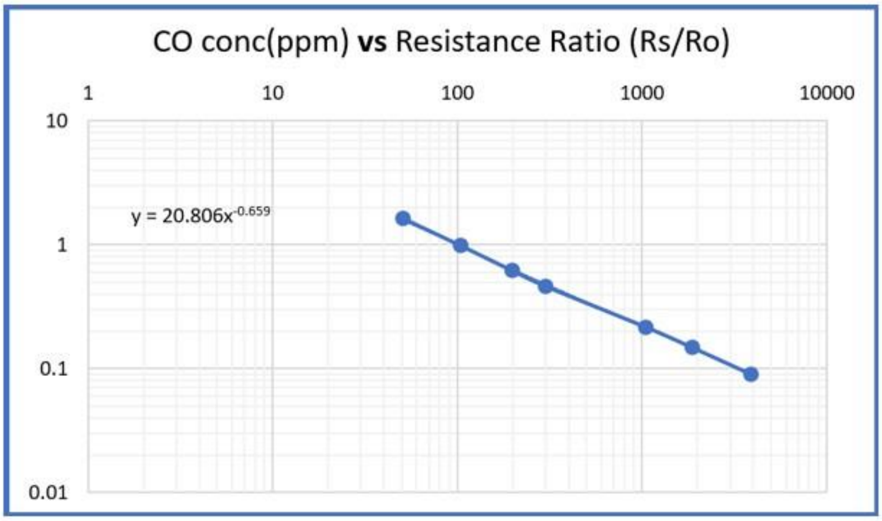


Figure 4.7: Best fit CO concentration characteristic curveThe equation of the best fit curve for CO was found as,

$$y = 20.806x^{-0.659} \qquad (4.3)$$

x – CO concentration in ppmy – Resistance ratio (R_S/R_O)
Equation 4.3 can be rearranged to find the CO concentration in any condition if the resistance ratio (R_S/R_O) is known. As a result, the required formula is as follows:

$$COconcentration[ppm] = \left[\frac{\frac{R_S}{R_O}}{20.806}\right]^{\frac{-1}{0.659}} \quad (4.4)$$

$$COconcentration[mg/m^3] = \frac{COconcentration[ppm] * 28.01}{24.45} \quad (4.5)$$

28.01 is the Molecular mass of CO and 24.45 is the Molar volume.

4.3 Air Quality Index (AQI)

According to the hazard degree and air pollution, the index is divided into six equal levels, namely, good, satisfactory, moderate, poor, very poor and severe which are represented by dark green, green, yellow, orange, red and maroon, respectively. The six grades and their related colors represent different effects on the human body. The detailed effects of the AQI are shown inTable 4.3[1].
The Air Quality Sub-Index of a pollutant item can be calculated using Equation 4.6 and Table 4.4 [1].

$$I_P = \left[\frac{(I_{HI} - I_{LO})}{B_{HI} - B_{LO}} * (C_P - B_{LO})\right] + I_{LO} \quad (4.6)$$

B_{HI} = Breakpoint concentration greater or equal to given concentration B_{LO} = Breakpoint concentration smaller or equal to given concentrationI_{HI} = AQI value corresponding to B_{HI}
I_{LO} = AQI value corresponding to $B_{LO}$$C_p$ = pollutant concentration
Finally the overall AQI can be calculated using the maximum operator function as in Equation 4.7.

$$AQI = Max(I_p) \quad (4.7)$$

(where; p= 1,2,...,n; denotes n pollutants)

For example: To calculate AQI on the basis of CO and ozone, calculate the sub-index for each parameter separately.

If the current concentration of CO is 4 mg/m^3, then referring to AQI range as per Indian standards B_{HI} = 10, B_{LO} = 2.1, I_{HI} = 200 and I_{LO} = 101.
Putting the values in equation and solving:
Sub Index, I_1 = [(200-101)/ (10-2.1)] (4-2.1) + 101 = 124.81

If the current concentration of O3 is 180 ug/ m^3, then referring to AQI range as per Indian standards B_{HI} = 208, B_{LO} = 169, I_{HI} = 300 and I_{LO} = 201.
Putting the values in equation and solving:
Sub Index, I_2 = [(300-201)/ (208-169)] (180-169) + 201 = 228.92

Finally, the overall AQI can be calculated using the maximum operator function as in Equation 4.7.AQI = Max (I_1,I_2) = Max(124.81, 228.92) = 228.92

Table 4.3: Health Statements for AQI Categories [1]

AQI	Associated Health Impacts
Good (0–50)	Minimal Impact
Satisfactory (51–100)	May cause minor breathing discomfort to sensitive people
Moderate (101–200)	May cause breathing discomfort to the people with lung disease such as asthma and discomfort to people with heart disease, children and older adults
Poor (201–300)	May cause breathing discomfort to people on prolonged exposure and discomfort to people with heart disease with short exposure
Very Poor (301–400)	May cause respiratory illness to the people on prolonged exposure. Effect may be more pronounced in people with lung and heart diseases
Severe (401-500)	May cause respiratory effects even on healthy people and serious health impacts on people with lung/heart diseases. The health impacts may be experienced even during light physical activity

Table 4.4: Breakpoints for AQI Scale 0-500 (units: µg/m^3 unless mentioned otherwise) [1]

AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m^3)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.6 –1.0
Moderate (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10.1-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17.1-34	801-1600	1201-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

V. Results and Discussions

Figure 5.1 shows the experimental setup developed for the detection of CO and NH_3 concentration in the ambience. The setup consists of a microcontroller board Raspberry Pi Pico W, Arduino UNO R3 SMD, MQ-7 CO gas sensor module, MQ-135 gas sensor, DHT22 temperature and humidity sensor, a buzzer, indication LEDs and a voltage regulator LM7805. The readings were observed in the lab ambience. Pico W board and the Arduino UNO were powered through the USB cable connected to a laptop. A rechargeable battery along with voltage regulator was used to power the sensor modules at 5V. The measured concentrations, the AQI value, ambient temperature and humidity values are made to be displayed on an LCD (Liquid Crystal Display). An LED (Light Emitting Diode) glows depending on the AQI value. The colour of the LED that glows depends on the Table 4.3. A buzzer beeps when the AQI value exceeds moderate levels. Figure 5.5 shows the demonstration model of the project. The information acquired in this manner is uploaded to the ThingSpeak cloud platform and shown as a plot with respect to time in the Figures 5.2, 5.3 and 5.4.

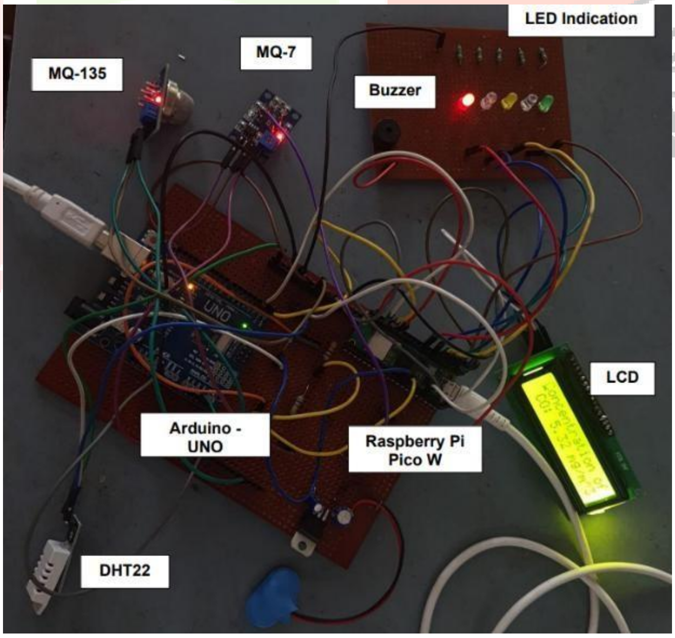


Figure 5.1: Experimental Setup

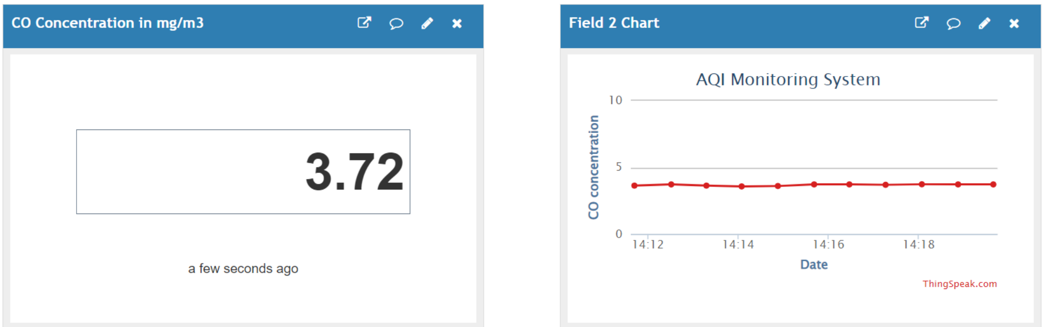


Figure 5.2: Data on Cloud - CO concentration in mg/m^3

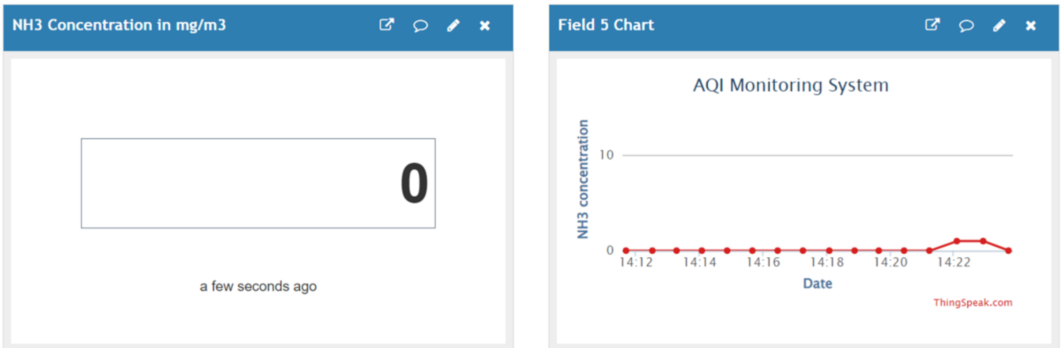


Figure 5.3: Data on Cloud – NH_3 concentration in mg/m^3

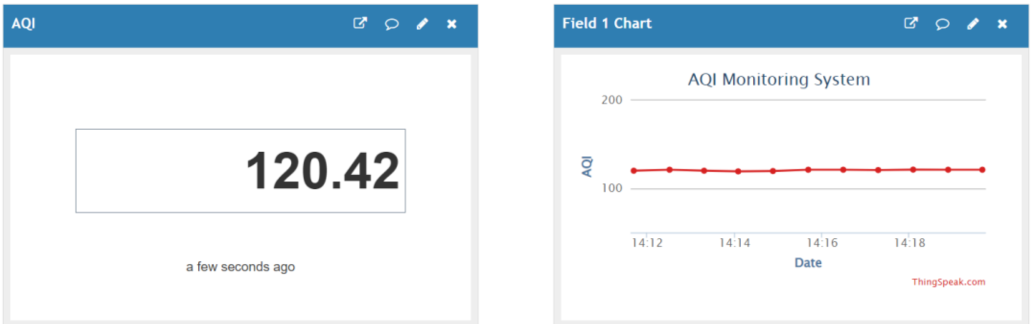


Figure 5.4: Data on Cloud - AQI

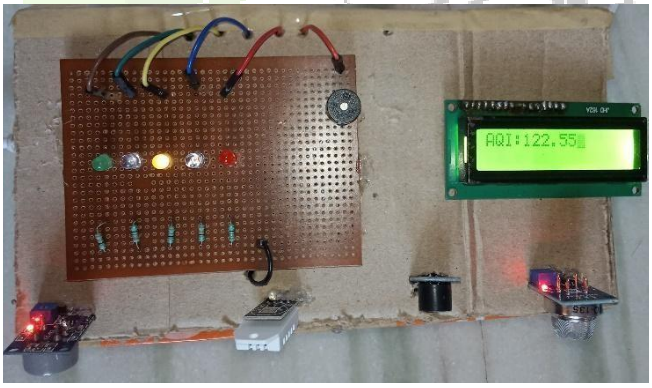


Figure 5.5: Demonstration Model

VI. Conclusion

Air pollution has been producing different effects to public health as a result of population growth, urbanization, cars, and industrial operations. The objective of the study is to give a justification for safeguarding public health from the harmful impacts of air pollutants, to eliminate or decrease exposure to hazardous air pollutants, and to direct national and local authorities in their decision-making about pollution control. The Air Quality Index can provide a clear picture of the surrounding air and the major pollutants that are most responsible for the air's quality. According to Central Pollution Control Board (CPCB) break point consideration, the AQI is determined. An AQI system based on the maximum operator function (choosing the maximum of sub-indices of different contaminants as overall AQI) is implemented. For near real-time AQI dissemination, eight metrics (PM10, PM2.5, NO_2, SO_2, CO, O_3, NH_3, and Pb) with short term standards should be considered.

A sensor was used to determine CO concentration, heater cycle requirements were studied and satisfied by giving a PWM signal generated by Pico W. To extract the equation from the gas's sensitivity characteristics curve, additional tools such as WebPlotDigitizer and Microsoft Excel's trendline function were used. Another sensor was used to measure ammonia. Using the MQ-135 library available for Arduino concentration of NH_3 gas is measured and sent to Pico W using UART transmission. Utilizing the Wi-Fi from the Pico W board information was uploaded to the ThingSpeak cloud. A buzzer alert was also added to indicate the high levels of CO.

Apart from other air quality monitoring systems, the study aims to build a model which provides transparency to common man in terms of the polluting gases, indices and adverse effects in a readily understandable manner. This helps him to modify his daily activities to his betterment. Other gases such as particulate matter and ozone gas can also be measured. However, the limited stock and cost of the respective sensors will have to be considered before using.

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