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Influence of Temperature and Humidity on the Output Resistance Ratio of the MQ-135 Sensor

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Abstract*—Broadly, a sensor is an object whose purpose is to distinguish events and changes in its environment and then complement it with a corresponding output (typically optical or electric). Advancements in nanotechnology, micro-machinery and micro-controller platforms have expanded the usage of sensors beyond the traditional fields. Electrochemical gas sensors measure the concentration of a target gas by oxidizing or reducing it at an electrode and then computing the resulting current. MQ135 is a stable, lowelectrochemical gas sensor which uses SnO_2[1] as its sensitive material. The datasheet[1] claims that the MQ135 is suitable for CO_2, Alcohol, Benzene, NO_x, NH_3. While it is observed from the sensitivity characteristic graph[1] that the general sensitivity is roughly same for all gases. But, as CO_2 is the fourth most abundant gas in the earth's atmosphere, it is safely assumed that in a normal atmosphere, the sensor mostly detects CO_2. Limited usage of MQ135 in the past years is attributed to a very poor quality datasheet which caused many researchers to conclude the sensitivity characteristic graph to be a power function[2]. Further power regression is used to find appropriate scaling and exponential factors. Our research augmented this mathematical calibration of the sensor addressing the temperature and humidity characteristics highlighted in the datasheet. We incorporate this influence in the form of a scaling factor whose values are derived from the datasheet and a comparative analysis between the two formulas is performed. All mathematical derivation is finally designed into a self-sufficient algorithm.

***Keywords*—Sensors, Electrochemical Gas Sensors, Sensitivity Characteristics Graph, Power regression, MQ135**

I. INTRODUCTION

Sensors are nowadays used in everyday objects and have become a part of the everyday smart life. Applications range from machinery, airplanes, aerospace, cars, medicine, robotics etc. Sensor is an object which detects events and changes in its environment. Sensors can be classified as transducers as they quantify changes in their environment through various types of output, typically electrical or optical signals. The earlier notion of using sensors to measure the basic characteristics of an object has now extended to advance characteristics by inclusion of latesttechnologies like image, audio, video and RF signals.A gas detector is a sensor that detects the presence of particular gases in its ambience. Gas detectors can be classified [17] according to their operation mechanism as in Table I.

Table I: Categories of Sensors

Types	Methodology
Electrochemical	*Oxidation or reduction*
Infrared Point	*Radiation passing*
Infrared Imaging	*Active and passive*
Semiconductor	*Conductivity*
Ultrasonic	*Acoustic sensors*
Holographic	*Light reflection*

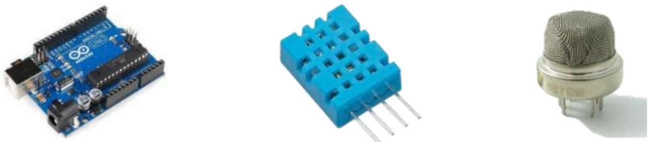
Semiconductor sensors detect gases by a chemical reaction that takes place when the gas comes in direct contact with the sensor. The change in resistance is used to calculate the gas concentration. MQ135 is a stable semiconductor gas sensor which has good sensitivity to harmful gases in wide range [1]. Datasheetof MQ135 is a poor indicator of its characteristics and functioning. A wide detection scope makes further analysis even difficult. DavideGironi[2] suggested mathematical formulation of sensitivity characteristics to find ppm values of different gases. The formulations thus used did not incorporate the effect of physical temperature and humidity and are not performing well under diverse conditions. In this study, the impact of thephysical parameters, temperature and humidity, is considered on ppm values of CO_2 gas as detected by the MQ135 sensor. This influence of temperature and humidity is further incorporated in the mathematical calibrationusing multiple regression analysis and also in the proposed algorithm to find ppm value of a gas.

The paper is further organised into section II providing related literature which gives details of the components used in the system, explaining the complete architecture and characteristics of MQ135 chemical sensor. Section III provides information regarding related work for finding ppm values of gases. Section IV provides the proposed system and algorithm for finding ppm values under the influence of temperature and humidity. Section V provides the experimental results of comparative study of two formulations by applying regression model to find mean square error (MSE) on data sample read by sensor. Further sections summarizes conclusion and future scope.

II. RELATED LITERATURE

A. Arduino UNO

The UNO is a microcontroller board based on the ATmega328P with a Flash memory of 32Kb and an Atmega16U2 which has been programmed as a USB-to-serialconverter. It has 14 digital input/output pins, 6 analog inputs, a 16 MHz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button [10].



Arduino UNO DHT11 Sensor MQ135 Sensor

Figure 1

B. DHT11 Temperature and Humidity Sensor

Digital temperature and humidity sensor (DHT11) is a composite sensor that gives a calibrated digital signal output of the temperature and humidity. It houses the dedicated digital modules collection technology and the temperature and humidity sensing technology, to ensure that the product has high reliability and excellent long-term stability [15].

C. MQ135 Semiconductor Sensor

MQ135 is a stable, low cost electrochemical gas sensor suitable for detecting a wide range of VOCs and gases. It is extremely sensitive to Ammonia, Sulphide and Benzene, also sensitive to smoke and other harmful gases. The MQ series of gas sensors use a small heater inside with an electro-chemical sensor and are usually used indoors at room temperature. Their calibration preferably requires a known concentration of the measured gas. Absence of any electronic components allow usage of both AC and DC voltages [1](Figure 2).

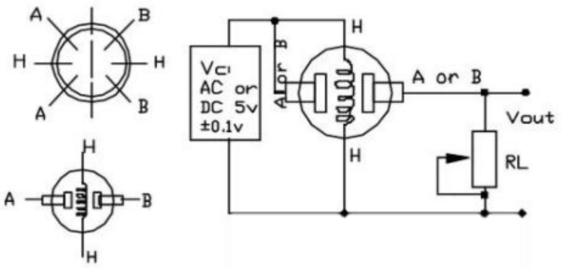


Figure 2: Configuration of MQ135 sensor

D. Limitationsof the MQ135 Sensor

The MQ135 gas sensor detects a number of gases like ammonia, CO_2, SO_2 etc. collectively but is unable to identify the individual gas concentration in a polluted environment. The sensor also uses an inbuilt heater to warm up air near thesensitive part for oxidation or reduction to take place [10]. It has been advised not to use this with a small battery source as it will quickly drain your battery. Sensor requires 24-48 hours of warm up time to start emitting stable readings of gas concentration.

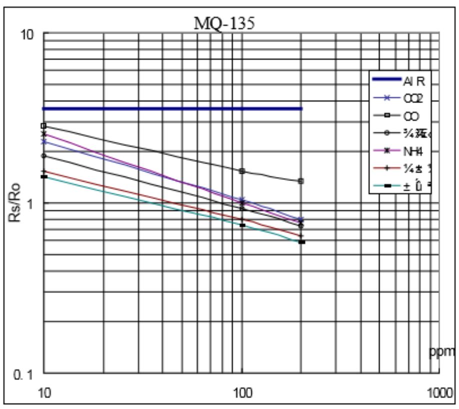


Figure 3: The typical sensitivity characteristics of the MQ-135. Temp: 20 Humidity: 65%, RL=20kΩ Ro: sensor resistance at 100ppm of NH3 in the clean air. Rs: sensor resistance at various concentrations of gases.

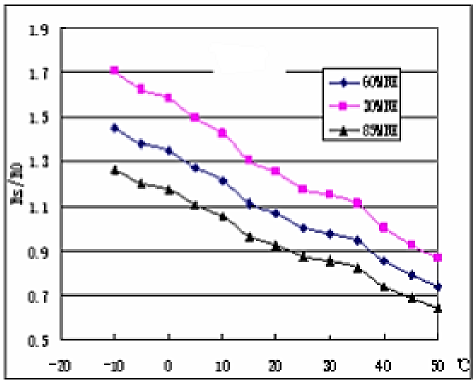


Figure 4: The typical dependence of the MQ-135 on temperature and humidity. Ro: sensor resistance at 100ppm of NH3 in air at 33% RH and 20 degree. Rs: sensor resistance at 100ppm of NH3 at different temperatures and humidity

Moreover the datasheet provided with the sensor does not provideclear information about the characteristics of sensor[1]. Thegraph in the Figure 3indicating the sensitivity characteristics of the sensor does not provide accurate readings for individual gases. Datasheet does not tell us much for detecting concentration scope for CO_2 gas, as the graph is onlyprovided from 0.1 to 100ppm. Datasheet provides little information about the temperature and humidity dependence of the output resistance of the sensor (Figure 4).

III. RELATED WORK

A. Gironi's Formulation

DavideGironi, a software engineer from "UniversitàdegliStudi", Milano worked on various aspects of the MQ135 Gas Sensor. He analysed the sensitivity characteristics of the MQ-135from the poorlydocumented datasheet of this sensor [2]. He used the graph (Figure3) to convert the output of sensor to the related ppm characteristics for the gas under test.

After studying the sensitivity graph of MQ135 (Figure3),Gironifelt that the resistance ratio of the sensor (R_S/R_O) and the gas concentration (ppm) are related as a power function,

y = a*x^b ……… (1)

Using power regression, he obtained the scaling factor (a), and the exponential factor (b), for the gas. He used both these parameters to calculate the corresponding concentration. He also proposed that the calibration of $R_S$can be done in clean air once stable readings are being received from the sensor,

R_S = R_O * sqrt(a/ppm, b)...…..(2)

The concentration scope of a particulargas was identified using datasheet leading to the computation of the limit for R_S/R_O,

R_S/R_O_limit = (ppm/a) ^ (1/b) …… (3)

Finally, a Matlab script was usedfor power regression and polynomial curve fitting. Raw values were converted to calculated resistance and an arbitrary value of R_O, was used in the mathematical formulation of the microcontroller. The R_O calibration is very important because every MQ135 sensor is different from the other and they require individual calibration.

IV. PROPOSED SYSTEM

The proposed system consists of the MQ135 sensor, Microcontroller Development Board (Arduino UNO), DHT-11 Temperature and Humidity Sensor and Software support with display. The block diagram of overall system is given in Figure 5 indicating the steps design to convert analog signals from MQ135 sensor and DHT11 to their corresponding values in PPM and temperature and humidity. Designincludesdevelopmentof thecodeforArduinomicrocontrollerand a MATLAB script for plotting Serial data from Arduino directly to MATLAB.Excel is used to producethe real-timegraphplottingofthegas concentrationdetectedfortheanalysis and calibration purpose.

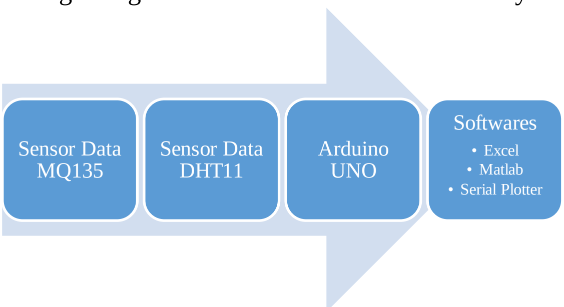


Figure 5: Block diagram of System

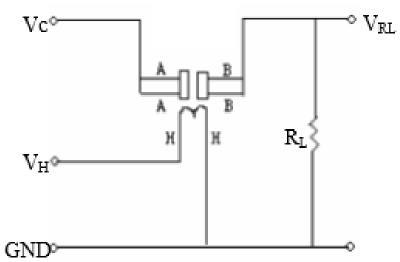


Figure 6: Test circuit for MQ135 sensor

A. Architecture

The sensitive material used in the MQ135 Gas Sensor is SnO_2 (Tin Dioxide) [3], which has lower conductivity in clean air. When the target combustible gas exists in the sensor's environment, the sensor's conductivity increases alongwith increasinggas concentration. A simple electro-circuit is used to convert change of conductivity to correspond output signal of gas concentration was shown in Figure 6.

The output of MQ135 is an analog signal and can be read with an analog input of the Arduino. The sensor need to be put two voltages: one is heater voltage (V_H) and the other is test voltage（$V_C$or 5V). V_H is used to supply certified working temperature to the sensor, while V_C is used to detect voltage (V_{RL}) on load resistance (R_L) which is connected in series to the sensor (Figure 6).

The proposed system circuit design is given in Figure 7. The 5V and GND pin of Arduino is connected to the power strip of the breadboard. Both DHT11 and MQ135 sensors receive power from the board only. Input from MQ135 and DHT11 is received on Analog Input 0 and Input 1 of Arduino respectively.

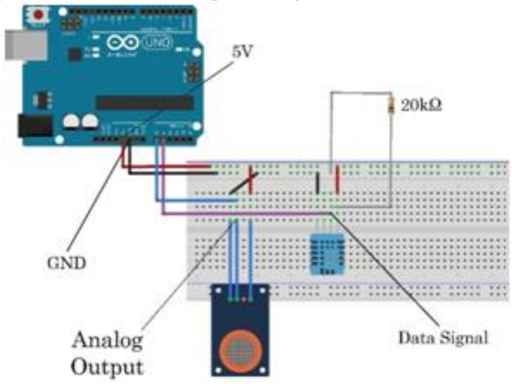


Figure 7: System Circuit Connection Design

B. Calculations

Arduino reads and produces output in analog value which is not a very useful parameter for gas concentration reading. This data must be converted to PPM (parts per million) values. First of all, conversion of the analog values(0-1023) to corresponding voltage values(V_{out})(0-5V) is done using:

$$V_{out} = \frac{\text{AnalogValue*5}}{1023} \text{……….} \qquad (4)$$

Resistance of sensor (R_S) is defined in the datasheet[1] of MQ135 as:

$$R_S = \left(\frac{V_{cc}}{V_{out}} - 1\right) * R_L \qquad \text{……..} \qquad (5)$$

$$= \left(\frac{1023}{\text{AnalogValue}} - 1\right) * R_L \quad \text{……..} \qquad (6)$$

Sensitivity Characteristics Graph given in the MQ135 Datasheet (Figure 3) is used to extract data for CO2.Power function gets the best fit for the extracted data, where *a* and *b* are the scaling and the exponential factor respectively, which implies

y = a*x*b

$$\text{ppm} = a*(R_S/R_O)\ \text{^}b \text{ …..} \qquad (7)$$

Power Regression Analysis on data using Excel, gives the values of *a* and*b* as:

a = 121.4517

b = -2.78054

The general sensitivity is roughly same for all the gases detected by MQ135. CO_2 is the fourth most abundant trace gas in the earth's atmosphere with approximately 400 ppm concentration [6], therefore it is safe to assume that in a normal atmosphere the sensor mostly detects CO_2.

After the Burn-in time (24-48 hours) of sensor, R_O is calibrated using the following equation:

$$R_O = R_S\text{*pow(a/ppm, 1/b) ……..} \qquad (8)$$

The proposed model incorporates the dependence of Temperature and Humidity on MQ135 sensor functionality (Figure 4). We evaluate the dependence of these parameters on the functioning of the MQ135 sensor using Multiple Regression Analysis which gives the following equation:

$$R_S\text{\_Scaling\_Factor}=1.6979-0.012t-0.00612h \text{ …(9)}$$

$$\text{Corrected}R_S = R_S/\ R_S\text{\_Scaling\_Factor…..} \qquad (10)$$

Where t and h are scaling factors for parameters for temperature and humidity. CorrectedR_S is the resistance of sensor under the influence of temperature and humidity.

C. Algorithm

```
setup( )
{ setAnalogPinforMQ135(analog0);
setAnalogPinforDHT11(analog1);
Serial.begin(9600);
}
loop( )
{  AnalogValue = receiveMQdata( );
```

```
   T = TempfromDHT11( );
   H = HumfromDHT11( );
Vout = convertanalogtovoltage(AnalogValue);
while(calibrationisnotcomplete)
{ RO = calculateRoValue(Vout, DefaultPPM);
    }
   RS = calculateRsValue(CaliberatedRO, Vout);
CorrectedRS = TempHumCalibRs(RS, T, H);
ppm = PPM(RS, RO, MQ_Scaling_Factor, MQ_Exponent_Factor);
Correctedppm = PPM(CorrectedRS, RO, MQ_Scaling_Factor, MQ_Exponent_Factor);
PlotDatainMatlab( );
SendDatatoSerialMonitor( );
SendDatatoExcel( );
}
```

V. EXPERIMENTAL DETAILS

Sensor Data is received from the Arduino through Serial Communication. Serial is used for communication between the Arduino board and a computer or other devices. All Arduino boards have at least one serial port (also known as a UART or USART): Serial. It communicates on digital pins 0 (RX) and 1 (TX) as well as with the computer via USB.

A. Analysis and Algorithm Evaluation

For performing additional analysis and extracting raw data, Excel has been used. Taking a small sample of data from the MQ135 sensor and DHT11 through analog inputs of Arduino UNO, the flow of the algorithm and the corresponding result is represented in the form of tables:

Table II: Raw voltage values received through the MQ135 sensor and corresponding temperature and humidity values

Time	Tempe rature	Humidity	Analog Value (MQ135)
19:29:53	25	20	219.0001
19:29:54	25	20	219.0001
19:29:55	25	20	219.0001
19:29:57	25	20	219.0001
19:29:58	25	20	218
19:29:59	25	20	218
19:30:01	25	20	218
19:30:02	25	20	218
19:30:03	25	20	219.0001
19:30:04	25	20	219.0001

Table III: Raw voltage values converted to resistance values and then the corresponding PPM. R_O was previously calibrated

Time	Resistance (R_S)	PPM
19:29:53	3671.23	264.69
19:29:54	3671.23	264.69
19:29:55	3671.23	264.69
19:29:57	3671.23	264.69
19:29:58	3692.66	260.45
19:29:59	3692.66	260.45
19:30:01	3692.66	260.45
19:30:02	3692.66	260.45
19:30:03	3671.23	264.69
19:30:04	3671.23	264.69

Table IV: The Temperature and Humidity correction factor is used and the Corrected Resistance and subsequently the Corrected PPM is evaluated

Time	Resistance (CorrectedRs)	Corrected PPM	Correction Factor
19:29:53	2878.27	520.71	1.28
19:29:54	2878.27	520.71	1.28
19:29:55	2878.27	520.71	1.28
19:29:57	2878.27	520.71	1.28
19:29:58	2895.07	512.35	1.28
19:29:59	2895.07	512.35	1.28
19:30:01	2895.07	512.35	1.28
19:30:02	2895.07	512.35	1.28

19:30:03	2878.27	520.71	1.28
19:30:04	2878.27	520.71	1.28

VI. RESULTS

Both the algorithms (Proposed and Gironi's) were evaluated simultaneously for a detailed comparative analysis. Gironi's algorithm while worked well at warm temperatures but failed when the temperature was lowered in similar conditions.
The sensor was kept in aclosed room with minimal ventilation and disturbance. The only factor that was changed (decreased) with time was Temperature of its surroundings. Though small changes in PPM values are expected in a non-laboratory environment yet constant decrease in values indicate a trend and thus, a dependence on temperature. Also, the PPM values received from Gironi's Algorithm went below 300 which is unexpected behaviour in an indoor environment in Delhi(500-1000ppm) [16] (Figure 8).

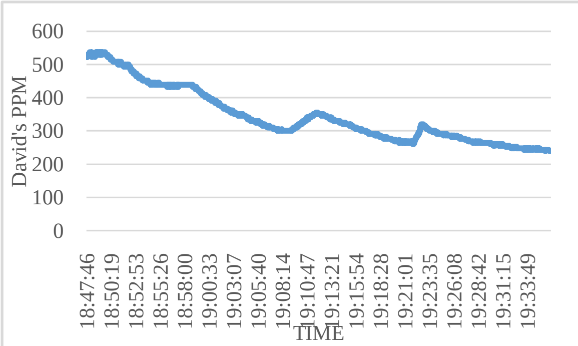


Figure 8: PPM Concentration vs Time, evaluated using Gironi's Algorithm

Our algorithm took reference from the datasheet [1] regarding this dependence on temperature and humidity and incorporated an appropriate scaling factor for the resistance value which was assessed through multiple regression analysis in excel.

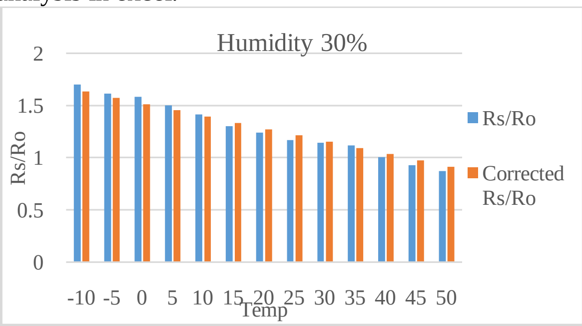


Figure 9: Rs/Ro vs temperature using datasheet and proposed equation at 30% Humidity

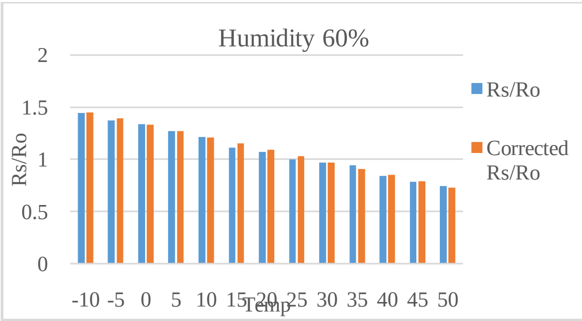


Figure 10: Rs/Ro vs temperature using datasheet and proposed equation at 60% Humidity

The graphs(Figure 9 and 10) show the relation between R_S/R_O scaling factor from datasheet (Figure 4) and R_S/R_Oscaling factor formed using the equation received from regression analysis (Equation 9) for humidity 30% & 60%.Negligible variance between the two series profess the authenticity of the equation when compared with the datasheet and further authenticate the results of the regression analysis.
The Scaling Factor evaluated using Equation 9 is used to evaluate Corrected Resistance and finally the Corrected PPM. As a result the graph formed (Figure 11) has a lower slope-0.104 for its linear trend line as compared to -0.1192 (Figure 8) indicating lesser change ratio with changing temperature. This indicates that the dependency of the sensor on temperature and humidity has been accounted for to a certain extent.

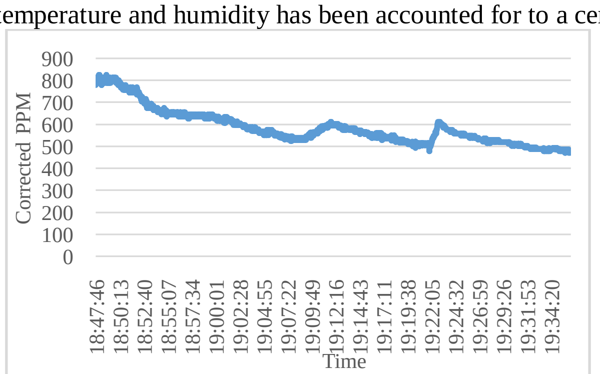


Figure 11: PPM Concentration vs Time, evaluated using Our Algorithm

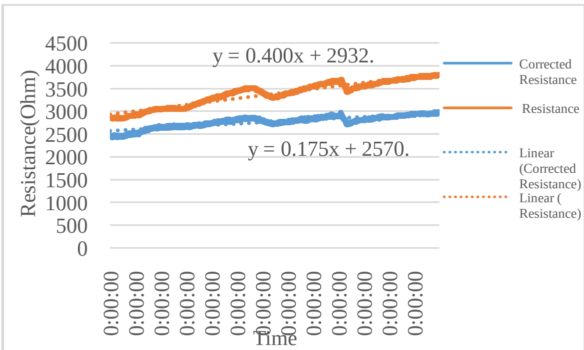


Figure 12: Corrected Resistance vs Resistance with trendlines

Similar observations(Figure 12) were made when plotting the two resistances- Resistance: Received from the sensor, Corrected Resistance: Resistance with the temperature and humidity scaling factor. The slope of the Corrected Resistance curve (0.1758) is considerably lower than the slope of the Resistance curve (0.4002) indicating a smaller change rate with time or temperature.

VII. CONCLUSION AND FUTURE SCOPE

The comparative analysis of the resistance of the sensor and ppm value of CO_2 concentration evaluated using Gironi's algorithm and the proposed algorithm shows both the need and the feasibility of the proposed system. The sensor readings are recorded as analog signals using an Arduino UNO in an indoor closed environment under non laboratory conditions. This providesthe data needed for evaluating sensor resistance and the PPM value of CO_2 using both the algorithms at varying temperature and humidity. It was observed that the values of resistance and PPM are more stable and relatable using proposed algorithm as compared to Gironi's which ascertains the significant effect of temperature and humidity on the functionality of the MQ135 sensor. Also the negligible variance among the temperature and humidity factor extracted from the datasheet and the factor received from the proposed equation further depicts the authenticity of the system. Further analysis and astute parametric calibration can be done in a controlled laboratory environment. Calibration done in a polluted environment of known CO_2 concentration will prove to be more accurate and reliable. Other factors that affect the functioning of the MQ135 sensor in a dynamic environment can be assessed. The behaviour of CO_2 at outdoor conditions should also be reviewed with indoor conditions to better observe the functionality of the sensor. Incorporation of even more accurate devices for temperature and humidity sensing in the sensor's environment than DHT11 will also be covered in future. Moreover, the accuracy and stability of ppm values under variant temperature and humidity conditions can be compared with data received from more accurate CO_2sensors like Infrared NDIR sensors under similar conditions to further authenticate the proposed approach.

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