MESH PLOT- BASED ANALYTICAL SELECTION OF OPTIMAL MQ-SERIES GAS SENSOR PARAMETERS

Adebimpe R. Ajayi
Department of Computer Engineering, University of Ilorin, Kwara State, Nigeria
ajayi.ra@unilorin.edu.ng

Olalekan F. Adebayo
Department of Computer Engineering, University of Ilorin, Kwara State, Nigeria
adebayo.of@unilorin.edu.ng

Mark O. Ajayi
Department of Computer Engineering, LAUTECH, Ogbomoso, Oyo State, Nigeria
mark.newness.edu@gmail.com

ABSTRACT

Metal Oxide Semiconductor or MOS-Type gas sensors are a type of sensors that can detect presence of some volatile, oxidizable or reducible substances in an environment. The sensitivity of these sensors depend on the selection of the appropriate parameters in terms of the sensor resistance in clean air (R_o) and the load resistance value (R_L). A mesh plot analytical method for determing these parameters is presented in this paper. The model equation for MQ-135 sensor as a case study was derived and this was used to generate the mesh surface plot of the various relationships existing between the different parameters leading to the selection of the optimal value that can give a useful sensor output voltage. The mesh surface plot of R_o (Ω), R_s (Ω) and concentration (ppm) and as well as the plot of R_L(Ω), V_{R_L}(V) and R_s(Ω) were critically examined. The result of the simulation shows that, for optimal sensor output in MQ-135 sensor, the R_o value must be selected to be at a value of 30kΩ and the load resistor R_L at a value of 47kΩ for effective sensor output.

Keywords: MQ-series Gas sensors, Sensor Resistance, Concentration and Output Voltage

1 INTRODUCTION

Metal Oxide Semiconductor or MOS-Type gas sensors are a type of sensors that can detect the presence of some volatile, oxidizable or reducible substances in an oxygen environment (Javier, Jose and Rafael, 2020). Metal oxide semiconductors have been found useful in food quality control (Peris and Escuder-Gilabert, 2009), hazardous gas detection (Chadry and Suryani, 2018), environmental monitoring (Capelli and Sironi, 2017; Capelli *et al.*, 2014), air quality monitoring, medical treatment and diagnosis (Chen *et al.*, 2013). MQ-series gas sensors are commonly used in this regard owned to their high sensitivity to target gases and their stable and long life chracteristics (Ornek and Karlik, 2012). These sensors are electrical conductivity sensors i.e. their active sensing layer changes when they come in contact with the target gas (Lin *et al.*, 2019). The MQ-series gas sensors are resisitive sensors; their resistance changes when the concentration of the measured gas changes and the relationship between the sensor resistance and concentration of target gas is non-linear (Xiao *et al.*, 2012). When connected to a basic electrical circuit, a certain voltage that depends on the physical magnitude of the target gas can be measured (Nayyar *et al.*, 2016; Ponzoni *et al.*, 2017).

The resistance of MQ-series gas sensors varies with concentration of the target gases (Fisher, 2013); hence, appropriate values of sensor resistance R_s (Ω), Sensor resistance in clean air R_o(Ω) and the Load Resistance R_L(Ω) must be selected for optimum sensor sensitivity.

This study aims to determine the resistance values i.e. the sensor resistance in clean air (in the absence of the target gas) R_o, Sensor resistance when exposed to the target gas R_s and the load resistance R_L for MQ-series gas sensors using MQ-135 as a case study to ensure optimal sensitivity by using the surface mesh plot analysis method. The selected sensor for this study, MQ-135 can detect carbon monoxide (CO) gas. It is used mostly in air quality control equipment and can also detect a number of gases such as Ammonia, Alcohol, Benzene, smoke and Carbon dioxide (Kalra *et al.*, 2016). The choice of MQ-135 sensor in this study is owned to its high sensitivity to toxic gases such as carbon monoxide (Abbas *et al.*, 2020) and the range of gas in ppm it can detect which is 10ppm – 1,000ppm.

2 RELATED WORKS

Sukhdev *et al.* (2022) presented a mathematical model to show the relationship between ambient temperature and relative humidity on Metal Oxide chemoresistive gas sensors. The model showed an exponential relationship exist to ambient temperature and a linear relationship to relative humidity. An analytical method to determine the load resistance value for MQ-series gas sensor using MQ-6 as a case study was presented by Ajiboye *et al.* (2021). The study presented a model equation for determining sensor circuit sensitivity and power dissipation. The study shows that sensor sensitivity varies with load resistance. The behaviour of MQ-series gas sensors was studied and presented in Fisher (2013). The sensors investigated were MQ-2, MQ-4, MQ-6, MQ-7 and MQ-9. The relationship between the sensor signal as a function of gas concentration and the sensitivity resistance was established. The relationship was described as a logistic function. Moreso, it was found that the resistance across the sensor itself is strongly dependent on the voltage drop across it and its reference atmosphere. A structured method of determining the load resistance value for MQ-series gas sensors for any given gas concentration was presented in Ajiboye *et al.* (2022).

3 SYSTEM DESIGN

3.1 MQ-series Gas Sensor Model Equation

Figure 1 shows the MQ-series gas sensor electrical circuit from where the model equations (1) and (2) were derived by applying the Voltage Divider Rule. This simple electrical equivalent circuit is used to convert the sensed gas concentration to a voltage value across the load resistor (Ajiboye *et al.*, 2021).

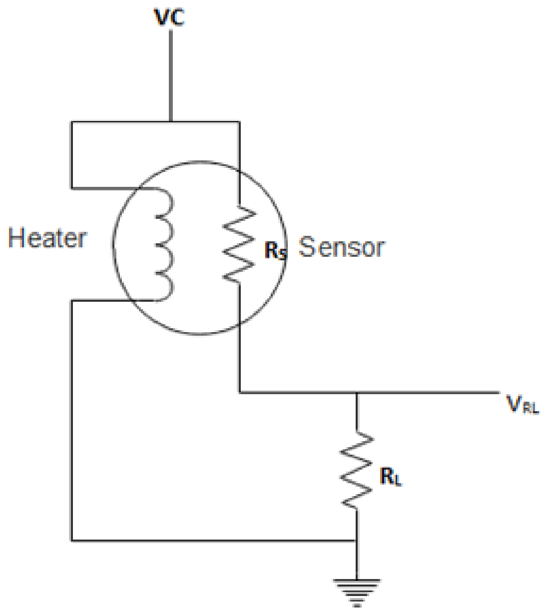

Figure 1 : MQ-series Gas Sensor Measurement Circuit (Jaycon Systems, 2018**)**

$$V_{R_L} = \frac{R_L}{(R_s + R_L)} \times V_C \ (V) \quad (1)$$

$$R_s = \frac{\left(V_C - V_{R_L} \times R_L\right)}{V_{R_L}} (\Omega) \quad (2)$$

where::
V_{R_L} = the voltage drop across the load resistor
V_C = the circuit (input) voltage
R_L = the load resistance (Ω)
R_s = the sensor resistance at different concentrations of the target gases(Ω).

3.2 Sensor Resistance and Concentration Relationship

The load resistance determines the output voltage (V_{RL}) which is the analog input for each sensor. When the gas concentration increases, the conductivity of the resistance increases too, and so the surface resistance of sensitive body, R_s decreases proportionally (Neri, 2015); this relationship is as given in equation (3).
From the MQ-series gas sensor datasheet, the range of sensor resistance in clean air (R_o) varies between 30kΩ and 200 kΩ; range of detectable concentration varies between 10 ppm – 200 ppm. These two variables were used to determine the range of sensor resistance (R_s) using equation (3) (Ajiboye *et al.*, 2021).

$$R_s = 10^{\left((a \times log(x)) + \log(b) + \log(R_o)\right)} \quad (3)$$

where:
x = the concentration value in parts per million (ppm)
a = the slope of the line in the sensitivity characteristic curve and
b = the intercept of the line in the sensitivity characteristic curve.

3.3 Selection of R_o and R_s values

A three-dimensional mesh surface plot of the range of $R_o(\Omega)$ values, the concentration (ppm) values as given in the sensor's datasheet and the corresponding sensor resistance (R_s) obtained by employing equation (3) was generated using software. Using this mesh plot, appropriate R_o value that gave a reasonable range of sensor resistance (R_s) was selected.

In order to select the appropriate (R_o) value, the ranges of sensor resistance R_s under these conditions were observed:

(i) when the concentration is at minimum value of 10ppm and R_o is at minimum value of 30kΩ and when the concentration is at maximum value of 200ppm with R_o kept at minimum value

(ii) when the concentration is at minimum and R_o is at maximum and when the concentration is at maximum with R_o kept at maximum value.

3.4 Selection of R_L value

A three-dimensional mesh surface plot of the range of $R_L(\Omega)$ values as given in the sensor's datasheet, sensor resistance $R_s(\Omega)$ values and the corresponding output voltage (V_{RL}) obtained by employing equation (1) was generated using software.
The ranges of output voltage V_{RL} were also observed from the plot under the following conditions before selecting the right load resistance value.

(i) The load resistance value at minimum with the sensor resistance R_s at minimum value and also when the sensor resistance R_s is at its maximum value while keeping the load resistance value at minimum

(ii) The load resistance value at maximum value of with the sensor resistance R_s at minimum value and also when the sensor resistance R_s is at its maximum value while keeping the load resistance value at maximum.

4 RESULTS AND DISCUSSION

The three-dimensional mesh plot of R_o, concentration (ppm) and R_s is as shown in Figure 2 and from where the contents of Table 1 were extracted.

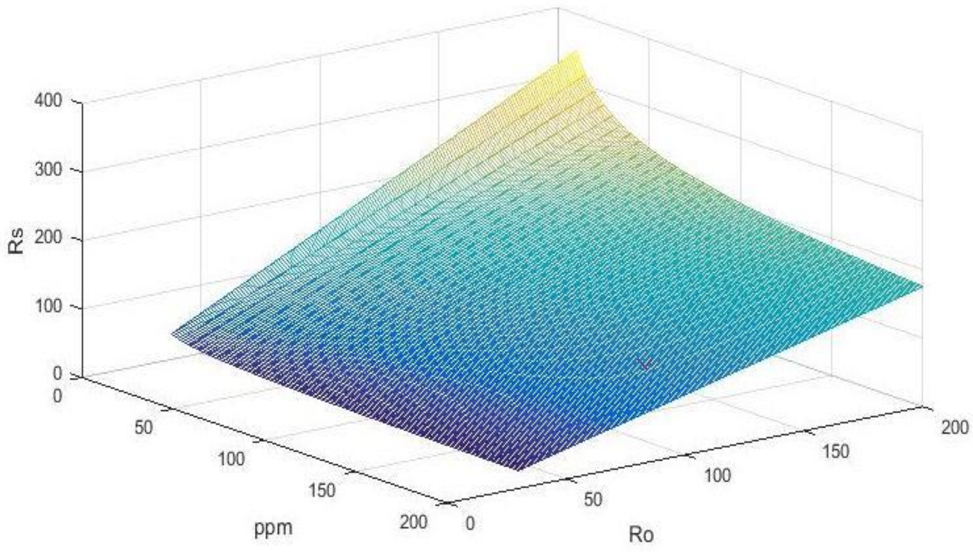

Figure 2: Surface Mesh Plot of R_o, concentration and R_s values for MQ-135

Table 1: MQ-135 Sensor Resistance, R_s values at different ranges of R_o and Concentration values

	Sensor Resistance Value (R_s)	
R_o Value	**At concentration level of 10 ppm**	**At concentration level of 200 ppm**
30kΩ	51.8kΩ	26.3kΩ
200kΩ	345 kΩ	176kΩ

From Table 1, for the range of concentration of 10 – 200ppm, the sensor resistance R_s varied from 345kΩ to 176kΩ which confirmed the decrease in sensor resistance with increased gas concentration. Also, at the minimum value of R_o , i.e. 30kΩ, the sensor resistance R_s at a minimum concentration of 10ppm was 51.8kΩ and 26.3kΩ at maximum concentration.

Figure 3 shows the mesh surface plot of R_L, R_s and V_{RL} to determine the load resistance and the corresponding output voltage significant to the microcontroller. Table 2 was extracted from the mesh plot.

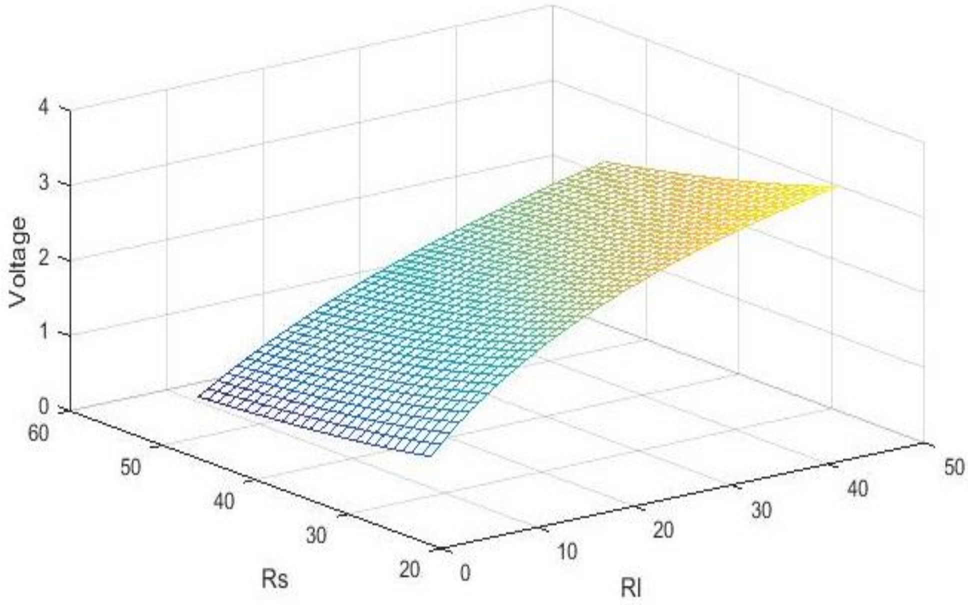

Figure 3: Surface Mesh Plot of R_L, R_s and V_{RL} at Minimum R_o for MQ-135

Table 2: Output Voltage values at minimum R_o value for MQ-135 Sensor

	Output Voltage (V)	
R_L value	**At R_s = 26.33kΩ**	**At R_s = 51.75kΩ**
5kΩ	0.79V	0.44V
47kΩ	3.21V	2.39V

From Table 2, at minimum R_o value and at minimum R_L value of 5kΩ, the voltage varies between 0.44V and 0.79V; this is very insignificant and may be seen as noise to the microcontroller. However, at maximum R_L value of 47kΩ, a significant voltage value ranging between 2.39V to 3.21V was recorded. Figure 4 also shows the surface mesh plot of R_L, R_s and V_{RL} at Maximum R_o for MQ-135. Table 3 shows that, at maximum R_o value when R_L is at a minimum, the voltage variable is between 0.071V and 0.13V. At maximum R_L value, the voltage varied from 0.59V to 1.05V.

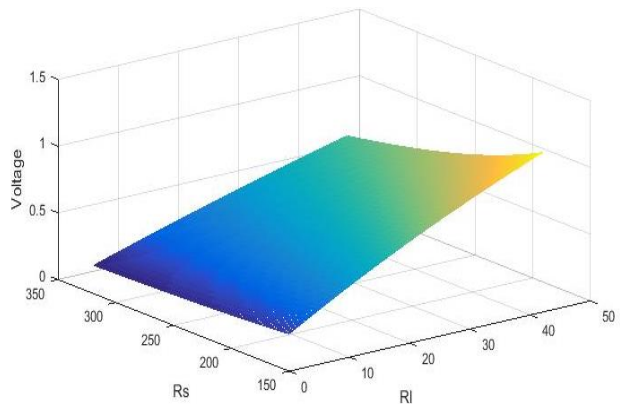

Figure 4: Surface Mesh Plot of R_L, R_s and V_{RL} at Maximum R_o for MQ-135

Table 3: Output Voltage values at Maximum R_o value for MQ-135 Sensor

	Output Voltage (V)	
R_L *value*	**At R_s = 176kΩ**	**At R_s = 345kΩ**
5kΩ	0.14V	0.07V
47kΩ	1.05V	0.59V

Hence, from the mesh plot analysis of Figures 2, 3 and 4 and Tables 1, 2 and 3, it was observed that the combination of Ro and RL values that gave a significant output voltage value of 3.25V were 30kΩ and 47kΩ respectively. This voltage value can however be amplified to meet voltage requirement for gas detection system.

5 CONCLUSION

This study presented a method for selecting appropriate resistance values for optimum MQ-series sensor sensitivity using mesh plot analysis. The method allows for every possible combination of sensor resistance in the absence of target gas (R_o) and concentration (ppm) which gives a corresponding range of sensor resistance (R_s) value and also combinations of the load resistance (R_L) and R_s values that can give a useful range of output voltage to the microcontroller for the selected MQ-series gas sensor. For MQ-135 sensor taken as a case study, R_o must be at a value of 30kΩ and the load resistor R_L at a maximum value of 47kΩ for effective sensor output.

6 ACKNOWLEDGEMENTS

We give thanks to Almighty God for the success of this work.

7 REFERENCES

[1] Abbas, F. N., Saadoon, I. M., Abdalrdha, Z. K. and Abud, E. N. (2020). Capable of gas sensor MQ-135 to monitor the air quality with Arduino Uno. *Int. J. Eng. Res. Technol,* 13(10), 2955-2959.

[2] Ajiboye, A. T., Opadiji, J. F. J., Ajayi, A. R. and Popoola, J. O. (2022). Determination of optimum load resistances of MQ-series gas sensor circuit for specific gas concentrations. *TELKOMNIKA (Telecommunication Computing Electronics and Control), 20*(1), 158-165.

[3] Ajiboye, A.T., Opadiji, J.F., Yusuf, A.O. & Popoola, J.O. (2021): Analytical determination of load resistance value for MQ-series gas sensors: MQ-6 as case study. *TELKOMNIKA Telecommunication, Computing, Electronics and Control.* 19 (2), 575-582.

[4] Capelli, L., & Sironi, S. (2017). *Monitoring odour emisssions from an oil & gas plant: Electronic nose performance testing in the field.* Paper presented at the Olfaction and Electronic Nose (ISOEN), 2017 ISOCS/IEEE International Symposium on.

[5] Capelli, L., Sironi, S., & Del Rosso, R. (2014). Electronic noses for environmental monitoring applications. *Sensors, 14*(11), 19979-20007.

[6] Chadry, R., & Suryani, A. I. (2018). Embedded system using field programmable gate array (FPGA) myRIO and LabVIEW programming to obtain data patern emission of car engine combustion categories. *JOIV: International Journal on Informatics Visualization, 2*(2), 56-62.

[7] Chen, S., Wang, Y., & Choi, S. (2013). Applications and technology of electronic nose for clinical diagnosis. *Open Journal of Applied Biosensor, 2*(2), 39.

[8] Fisher, A. (2013). Characterization of MQ-series gas sensor behavior. *Capstone Project Report.* Northern Illinois University.

[9] Javier Cervera Gómez, Jose Pelegri-Sebastia and Rafael Lajara(2020). Circuit Topologies for MOS-Type Gas Sensor. *Electronics*, 9, 525; doi:10.3390/electronics9030525

[10] Jaycon System (2018). Understanding a gas sensor https://jayconsystems.com/blog/understanding-a-gas-sensorMQ-135 - Gas Sensor Datasheet.

[11] Kalra, V., Baweja, C., Simmarpreet, D. and Chopra, S. (2016). Influence of temperature and humidity on the output resistance ratio of the MQ-135 sensor. *International Journal of Advanced Research in Computer Science and Software Engineering, 6*(4), 423-429.

[12] Lin, C., Xu, W., Yao, Q. and Wang, X. (2019). Nanotechnology on toxic gas detection and treatment. In *Novel nanomaterials for biomedical, environmental and energy applications*, 275-297.

[13] Nayyar A., Puri V., and Le D.-N. (2016). "A comprehensive review of semiconductor-type gas sensors for environmental monitoring," *Review of Computer Engineering Research*, 3, 55-64.

[14] Neri, G. (2015). First fifty years of chemoresistive gas sensors. *Chemosensors*, 3(1), 1-20.

[15] Ornek, O. and Karlik B. (2012) "An overview of metal oxide semiconducting sensors in electronic nose applications," in *Proc. 3rd Int. Symp. Sustain. Develop*, 506-515.

[16] Peris, M., & Escuder-Gilabert, L. (2009). A 21st century technique for food control: Electronic noses. *Analytica chimica acta, 638*(1), 1-15.

[17] Ponzoni A., Baratto C., Cattabiani N., Falasconi M., Galstyan V. and Nunez-Carmona E. (2017). "Metal oxide gas sensors, a survey of selectivity issues addressed at the SENSOR Lab, Brescia (Italy)," *Sensors*, 17, 714.

[18] Sukhdev, K., Harinarayanan, P., Kumar, U. S. and Baburaj, P. (2022). A Simplified Model for Calculating the Dependence of Ambient Temperature and Relative Humidity on Commercial Metal Oxide Chemiresistive Gas Sensors. *Sensors & Materials, 34*.

[19] Xiao Liu, Sitian Cheng, Hong Liu, Sha Hu, Daqiang Zhang and Huansheng Ning (2012). A Survey on Gas Sensing Technology. *Sensors*, 12, 9635-9665.