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Datsheet-based calibration study of the MQ-135 sensors for carbon dioxide (CO_2) and MQ-8 sensors for hydrogen (H_2)

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Abstract

This research conducted a datasheet-based calibration study using the MQ-135 sensor and MQ-8 sensor to measure carbon dioxide and hydrogen. The process of digitizing datasheet graphs into numbers that have a relationship between electrical quantities and physical quantities (R versus ppm) is carried out using webPlotDigitizer software. Based on the calculation results, a trendline of the power equation model has been obtained for the MQ-135 gas sensor and MQ-8 gas sensor respectively from the comparison of the x-axis (ADC) and y-axis (PPM), namely $y_{MQ-135} = 2 \times 10^7 x^{-3.108}$ with a value of $R^2_{MQ-135} = 0.9968$, and $y_{MQ-8} = 2533x^{-0.746}$ with a value of $R^2_{MQ-8} = 0.9875$. Based on the R^2 value or coefficient of determination for each sensor, it shows that the value is close to 1, so this shows that the trendline of the power equation model used matches the sensor datasheet. The equations y_{MQ-135} and y_{MQ-8} will then be entered into the Arduino IDE program as calibration values for the MQ-135 sensor and MQ-8 sensor to obtain measurement values that are in accordance with the standardized datasheet. To improve accuracy, calibration was also performed using a reference instrument, a Carbon Dioxide Detector for CO_2 and a C-200 Pen-Type Water Quality Meter for H_2, with average errors of 1.29488% and 29.81805%, respectively. The low error value for CO_2 indicates good compliance, while the high error for H_2 is due to limitations of the reference instrument. This method can be an alternative when resources are limited, provided that the limitations of the instrument are still considered.

1. Introduction

Global attention to the management of individual and human health namely related to air quality. Monitoring air quality and how to manage it is very important and is an activity that is very much needed in today's world [1, 2]. Contamination that occurs both indoors and outdoors caused by chemical, physical and biological aspects that can modify atmospheric characteristics is referred to as air pollution [3, 4]. Clean air has a big impact on human health, especially for those who have allergies and respiratory diseases such as asthma and lungs [5–7], plant growth [8, 9], animal growth [2–10], etc. Several activities that have the potential to be a source of air pollution are motorized vehicles containing carbon monoxide (CO) gas [11, 12], burning household waste containing carbon dioxide gas (CO_2) and methane gas (CH_4) [13, 14], industrial factory activities [15, 16], forest fires [17, 18], etc.

According to data from the World Health Organization (WHO) in 2019, almost 99% of the global population has breathed air that exceeds the WHO guideline limits and is very high in dangerous pollutants, especially in low- and middle-income countries [19], in addition to the combined effects of the gas population in the air is associated with 7 million premature deaths annually [20]. A study conducted by [21] in 2019 estimated that air pollution in Europe could reduce the average life expectancy by around 2.2 years with an annual per capita death rate of 133/100,000. The impact that air pollution has on society is indeed significant enough to be

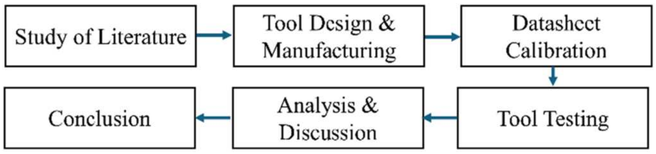

Figure 1. Research diagram.

discussed because it poses a major threat to health. Sources of air pollution can cause stroke [22, 23], heart disease [24, 25], lung cancer [26, 27], acute and chronic respiratory disorders [28–30], etc.

Several researchers continue to strive to develop and carry out air quality measures to determine the level of air quality in an area. In 2020 [31] conducted research on monitoring air quality, namely CO, CO_2, temperature and humidity based on the Internet of Things (IoT), which was implemented at Hanyang University of Korea. In 2022 [32] presented a prototype IoT system for monitoring traffic flow and air quality at low cost. In addition, [33] in 2019 monitored ozone, carbon monoxide, and sulfur dioxide using IoT with an Arduino Wifi module and the thingspeak cloud system. Several studies on measuring air quality, especially in gas form, can be measured using sensors with the MQ sensor type, the output of which is an analog signal which must be converted into parts per million (PPM) values [34–36].

The conversion process on the MQ sensor can be carried out in two ways, namely calibration using a standardized monitoring tool [37, 38] and using a calibration curve from the sensor data sheet [39] by applying appropriate regression values to obtain accurate PPM values. This type of MQ sensor is used because it has several advantages including being more sensitive and accurate [1, 40], cheap and easy to use [41], low power consumption [42], durable [43], and their small size [44]. This research uses the MQ-135 sensor to measure carbon dioxide levels and the MQ-8 sensor to measure hydrogen (H_2) levels in the air. Datasheet-based calibration studies were carried out using the datasheet owned by each sensor to find equations that could be used in Arduino uno IDE programming so that carbon dioxide (CO_2) and hydrogen (H_2) concentrations were obtained that were in accordance with standard measuring instruments. To improve the accuracy of the calibration process with the datasheet, two tools were used to validate the experimental results to support the theoretical findings. Hydrogen gas measurements used a C-200 pen-type Water Quality Meter to provide precise readings, while to measure Carbon Dioxide, a Carbon Dioxide Detector model M8 was used, known for its reliability in detecting the gas. These two tools were used specifically with the aim of validating and improving the reliability of the data recorded in the datasheet.

2. Method

2.1. Research flow

The stages carried out in this research are illustrated in a research diagram which can be seen in figure 1 below.

The literature study stage shown in figure 1 is the initial stage for carrying out parameters in preparing the theory for this research, then the design and manufacture of tools is carried out by starting to design the prototype and circuit circuits in the system. The tool was made using two MQ type sensors, namely the MQ-135 gas sensor and the MQ-8 gas sensor, an I2C LCD, and an Arduino UNO microcontroller. The next stage is creating a program using Arduino IDE software. The calibration process is carried out before the equipment is tested in the field to obtain data which will then be analyzed for further discussion of the results obtained.

2.2. Tool design and manufacturing

This prototype consists of two gas sensors, namely the MQ-135 gas sensor for measuring carbon dioxide and the MQ gas sensor for measuring hydrogen. Apart from that, the microcontroller used is Arduino IDE whose programming uses Arduino IDE. The carbon dioxide and hydrogen measurement results will then be displayed on the LCD I2C. An illustration of the tool workflow diagram can be seen in figure 2.

The system electronic circuit that connects the two MQ gas sensors with the Arduino IDE microcontroller and LCD can be seen in figure 3, while details of the connected pins can be seen in table 1 below.

2.3. Datasheet calibration

Characterization of the MQ-135 and MQ-8 gas sensors was carried out by comparing the tool with the instrument datasheet for each sensor. The first stage to characterize the datasheet is to prepare an image of the sensor data characteristics as shown in figure 4 as follows. The sensor datasheet was obtained from Hanwei Elcetronics [45, 46] which was then converted into image files (jpg), for example MQ8.jpg and MQ135.jpg. The

Figure 2. Tool Design.

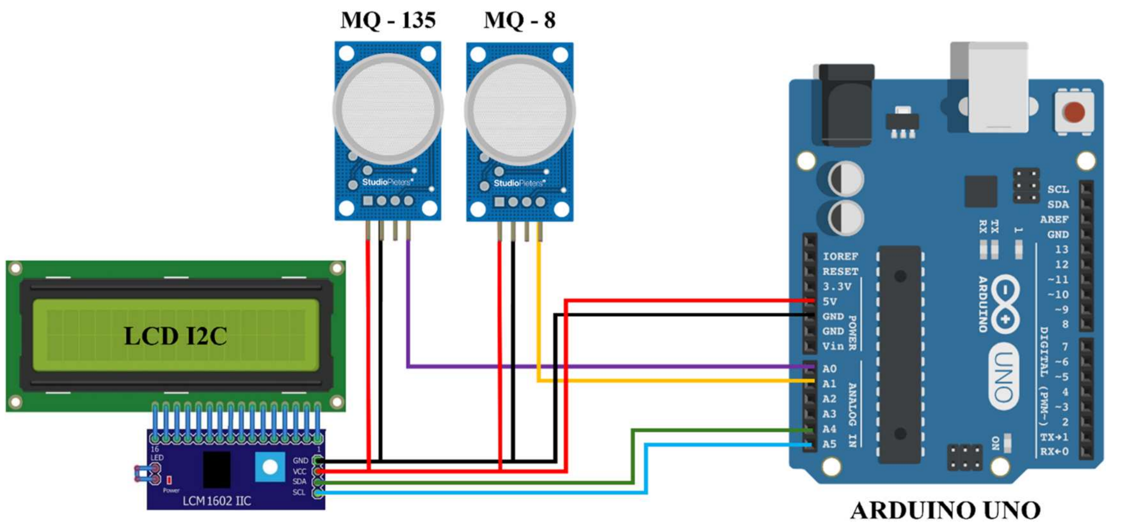

Figure 3. Electronic circuit system.

Table 1. Sensors data acquisition.

	Pin on tool	Pin on Arduino IDE
Sensor MQ-135	GND & VCC	GND & VCC
	Output	A0
Sensor MQ-8	GND & VCC	GND & VCC
	Output	A1
LCD	GND & VCC	GND & VCC
	SDA	A4
	SCL	A5

focus of the measurement characteristics of this MQ sensor is the MQ-135 sensor for measuring carbon dioxide and the MQ-8 sensor for measuring hydrogen.

Figure 4 above displays the response of the MQ-135 and MQ-8 sensors to various gases. The line representing CO_2 on the MQ-135 sensor shows the relationship between the sensor recitation ratio (Rs/Ro) and the CO_2 concentration, the higher the CO_2 oncentration in ppm units, the sensor resistance ratio (Rs/Ro) will decrease. This pattern is the basis for calibrating the MQ-135 sensors to measure CO_2 levels quantitatively. Meanwhile, the second graph focuses on the MQ-8 sensor which has high sensitivity to Hydrogen. The line representing H_2 on the graph represents the response of the MQ-8 sensors to changes in H_2 gas which shows an inverse relationship, namely the higher the H_2 concentration in ppm, the lower the resistance ratio (Rs/Ro). Therefore, this datasheet serves as the main guide in calibrating the MQ-8 sensors. The next step is the process of digitizing the

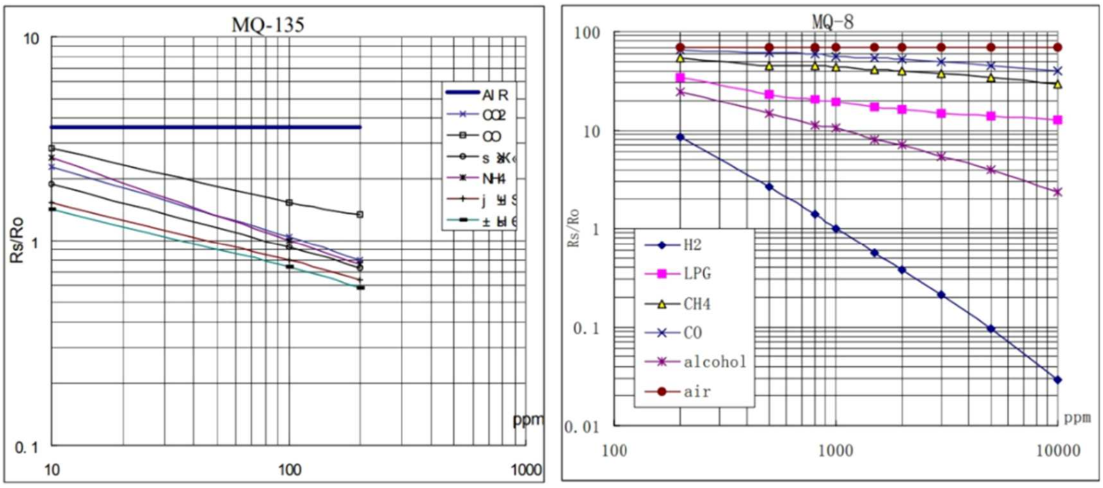

Figure 4. Data characteristics of the MQ-135 & MQ-8 gas sensors. Reproduced with permission from Hanwei Electronics Group Corporation.

graph into numbers that show the relationship between electrical and physical quantities (R versus ppm) using webPlotDigitizer software. The digitization process is as follows:

(a) Datasheet preparation

The digitization process begins by preparing the sensor datasheet image file to be analyzed, as shown in figure xx. Then, the file is uploaded to the webPlotDigitizer graph digitizing software.

(b) Coordinate axis calibration

Calibrate the *X*-axis (concentration) and *Y*-axis (Rs/Ro) by establishing clear reference points on the graph and setting the x- and y-axes to logarithmic values, as shown in figure 5. MQ-8 sensor: *x*-axis points, 100 to 10000, and *y*-axis points, 0.01 to 100. MQ-135 sensor: *x*-axis points, 10 to 100, and *y*-axis points, 0.1 to 10.

(c) Specific curve data extraction

Curve extraction on the MQ-8 and -135 sensors focused on the curves labeled H_2 and CO_2. The digitization stage was carried out by taking approximately 13 data points along the curve. Data collection was carried out with as much consistency as possible and at intervals that accurately represent the curve shape, as shown in figure 6.

(d) Data verification and export

The extracted data contains x- and y-value pairs representing gas concentrations and sensor resistance ratios. The data is then checked to ensure there are no anomalies or errors. Once validated, the data can be exported in formats such as .csv or .txt. This numerical data can be used for theoretical calibration through analysis, mathematical modeling, and re-visualization. The conversion formula for the voltage divider circuit and the ADC (8-bit) formula (interpolation formula) is as follows.

$$V_0 = \frac{R_s}{R_s + R_l} V_{cc} \tag{1}$$

$$ADC = \frac{1023}{V_{reff}} V_0 \tag{2}$$

The output voltage (Vout) entering the ADC pin is influenced by the MQ sensor resistance (Rs) and the load resistance (RL). For the MQ-135 sensor, the RL used is 20 k ohms, while for the MQ-8 sensor it is 10 k ohms. This Vout value is then converted by the ADC on the Arduino Uno into a digital value with a maximum range of 1023 and a reference voltage (Vreff) of 5 V. The results of the MQ sensor digitization can be seen in figure 7 below.

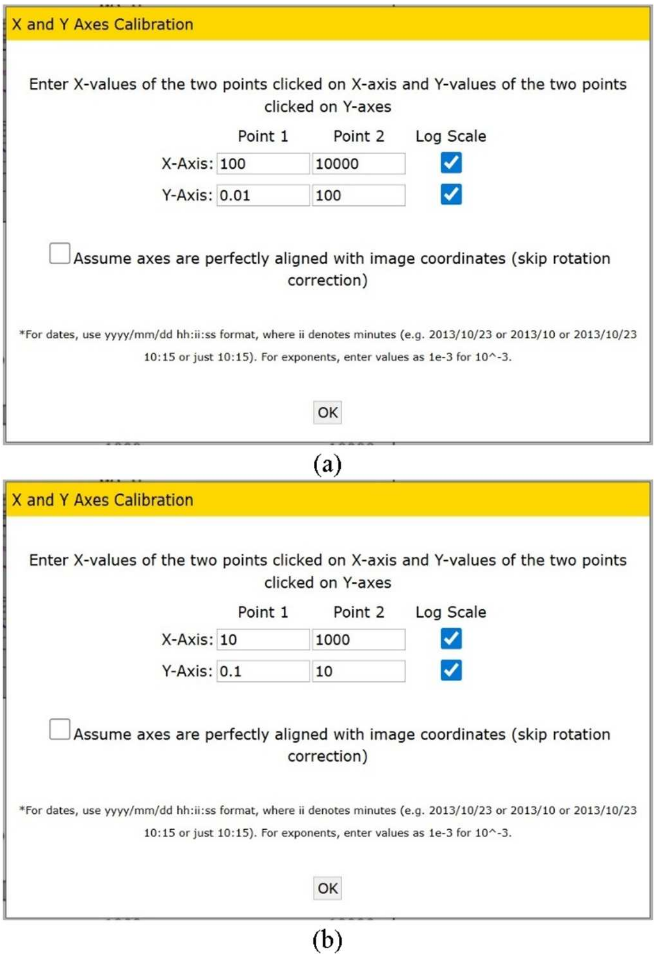

Figure 5. Coordinate: (a) MQ–8; (b) MQ–135 gas sensors.

2.4. Tool realization

The realization of the prototype of this tool can be seen in figure 8 as follows. There are two MQ gas sensors, namely MQ-135 to detect Carbon Dioxide and MQ-8 to detect Hydrogen gas, Arduino UNO as a microcontroller, I2C LCD screen functions as a visual interface that will display measurements from both sensors, connecting cables used to integrate all components and data communication between sensors, microcontrollers and LCDs, and a USB cable as a power supply cable to turn on the tool circuit to the Powerbank.

2.5. Data collection procedure

Data collection was conducted by comparing the theoretically calibrated instrument with a reference instrument, which would serve as a valid reference value or original value. The instruments used as comparisons were a Carbon Dioxide Detector for measuring CO_2 and a pen-type Water Quality Meter C-200 for measuring H_2. The constructed instruments were placed in an open environment, assuming normal gas concentrations. The CO_2 and H_2 concentrations displayed on the LCD screen of the MQ sensor were recorded simultaneously with the reference instrument. The collected data were then compared, and differences and errors were analyzed to verify that the equations from this theoretical method could be used as a calibration method for the MQ sensor.

3. Result and discussion

Digitalization of the MQ-135 and MQ-8 gas sensors using webPlotDigitizer software can be seen in table 2 as follows.

Based on table 2, then the voltage divider circuit formula and ADC (8 bit) formula (interpolation formula) are converted using equations (1) and (2) with the values of R_0, R_1, and V_{cc} on the MQ-135 gas sensor respectively being 1 KΩ, 20 KΩ, and 5V, while for the MQ-8 gas sensor they are 1 KΩ, 10 KΩ, and 5 V respectively.

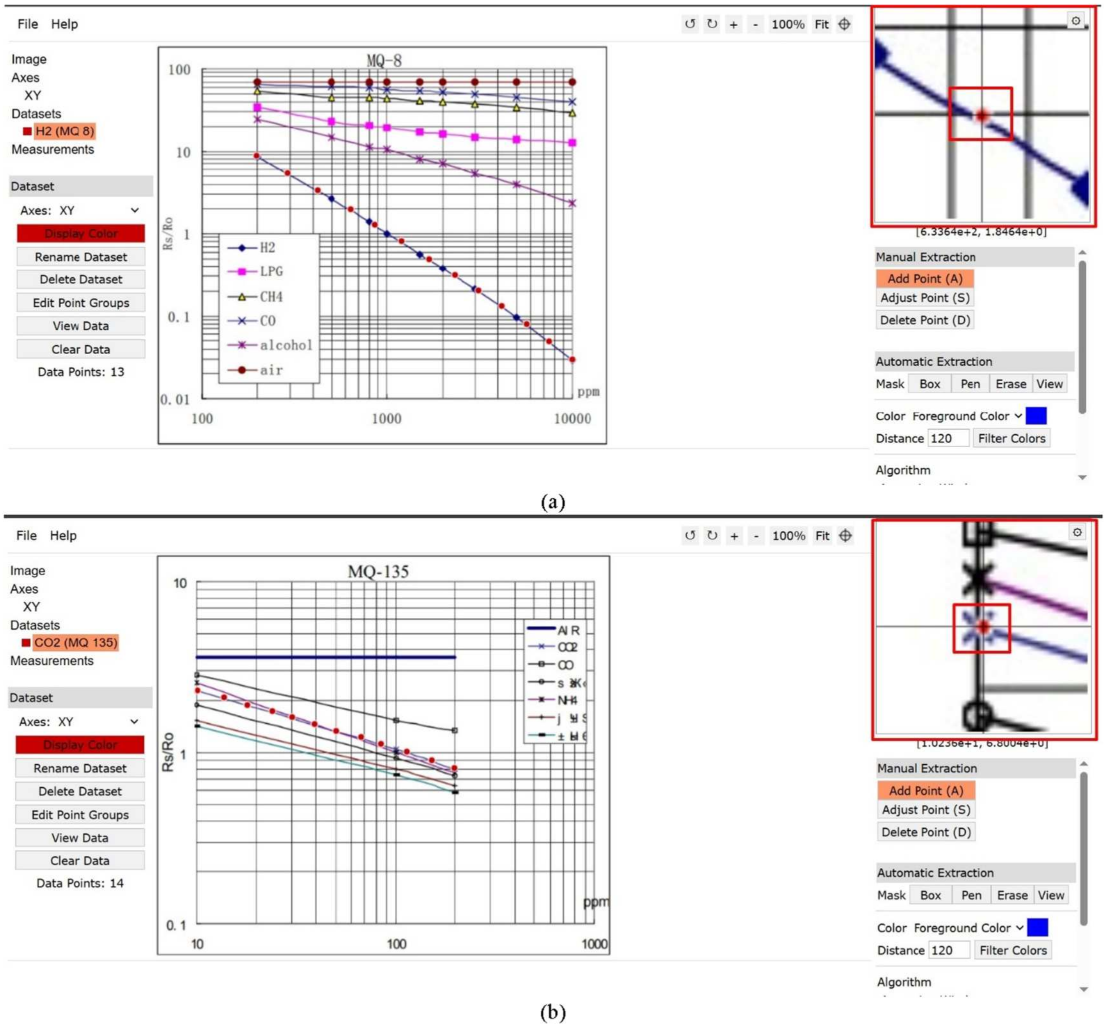

Figure 6. Data Extraction: (a) MQ-8; (b) MQ-135 gas sensors.

The results of these calculations then produce R_s, V_0 and ADC values which can be seen in tables 3 and 4 as follows.

The data presented in tables 3 and 4 are the results of theoretical calibration to determine the characteristics of the MQ-8 and MQ-135 sensors. The graph maps the relationship between gas concentration in ppm and the electronic response that can be measured by the sensor. The calculation process for this theoretical calibration uses equations (1) and (2). If we look at the MQ-135 sensor value in table 3, the CO_2 concentration value will increase exponentially from 10,236 ppm to 198,162 with the sensor resistance ratio (Rs/Ro) decreasing significantly from 2.57 to 0.811. This change in resistance is the sensor's physical response to the absorption of gas molecules that change the conductivity of the material. This change resulted in a decrease in the output voltage Vo from 0.507031 to 0.194849 V and the ADC value from 103.73860 to 39.86608, while the value of the MQ-8 sensor in table 4 the H_2 concentration value also increased from 19.7211 to nearly 1000 ppm, this resulted in the Rs/Ro value also dropping from 8.200 to 0.027. The MQ-8 sensor is very sensitive to hydrogen gas, so the decrease in the Rs/Ro value will be directly proportional to the decrease in the output voltage Vo and the ADC value. Based on the patterns in tables 3 and 4, a mathematical model or calibration curve can be built to convert the ADC readings from the device into actual gas concentrations as shown in figures 9 and 10.

The calibration equation obtained for the MQ-135, and MQ-8 sensors is a non-linear regression model in the form of a power equation, namely $y = ax^b$. This model is generated by selecting the Power type trendline in Excel, which performs a logarithmic transformation on the data (log–log transformation) and calculates the parameters a and b using the least squares method. The values of a and b can be directly seen from the displayed equation, while R^2 indicates the level of fit of the model to the data.

Based on the graphs in figures 9 and 10 the equation for the MQ-135 gas sensor is obtained from the comparison of the *x*-axis (ADC) and *y*-axis (PPM). namely $y_{MQ-135} = 2 \times 10^7 x^{-3.108}$ with the value of $R^2_{MQ-135} = 0.9968$, while for the MQ-8 gas sensor the comparison equation for the *x*-axis (ADC) and *y*-axis

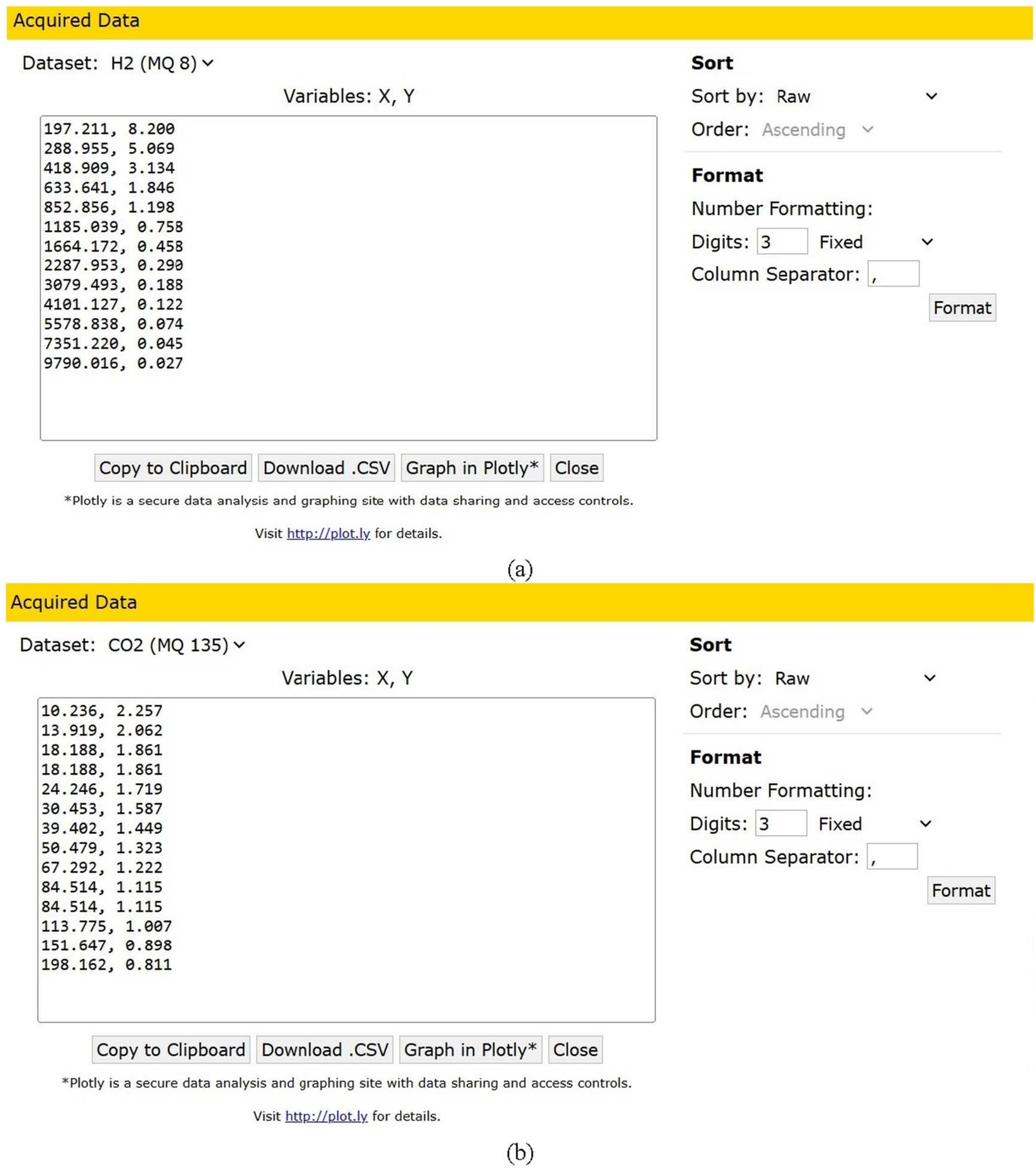

Figure 7. Data: (a) MQ-8; (b) MQ-135 gas sensors.

(PPM) is obtained. namely $y_{MQ-8} = 2533x^{-0.746}$ with the value of $R^2_{MQ-8} = 0.9875$. Based on the R^2 value or coefficient of determination which ranges from 0 to 1. Each of these sensors show that the value is close to 1 so this shows that the trendline of the power equation model used matches the sensor data sheet. The equations y_{MQ-135} and y_{MQ-8} will then be entered into the Arduino IDE program as calibration values for the MQ-135 sensor and MQ-8 sensor to obtain measurement values that are in accordance with the standardized datasheet. Implementation of the equations y_{MQ-135} and y_{MQ-8} in the Arduino IDE program results in measurements of carbon dioxide (CO_2) and hydrogen (H_2) levels measured in the air which can be seen in tables 5 and 6 below.

The results of carbon dioxide (CO_2) measurements using the MQ-135 sensor and hydrogen (H_2) using the MQ-8 gas sensor are shown in tables 5 and 6. Based on the data provided, the detected CO_2 concentration ranged from 451 PPM to 471 PPM, while the H_2 concentration ranged from 0.032 PPM to 0.059 PPM. Although there were fluctuations, the detected values showed the stability and consistency of measurements from both sensors. The detected gas concentration values were in the safe category for the air environment. Based on existing research, carbon dioxide concentrations in the air with values below 5,000 PPM are considered safe for human health [47–49], while hydrogen concentrations in the air must be maintained below 4% (40,000 PPM) to prevent explosion hazards [50–52].

The results of the MQ sensor measurements with the comparison tool shown in tables 5 and 6 have an average error value in the measurements, namely: 1.29488% for the MQ-135 sensor error with a Carbon

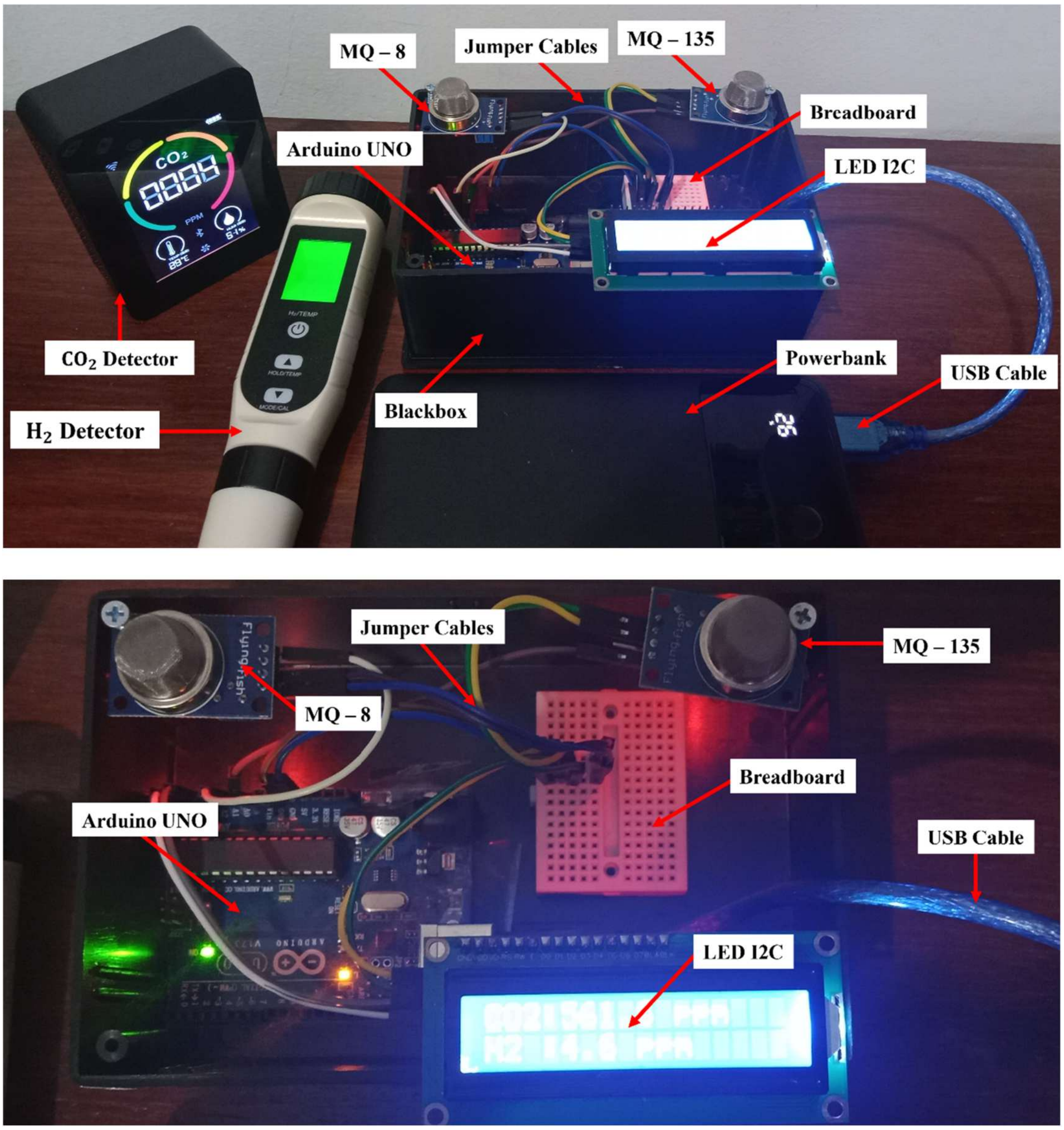

Figure 8. Tool realization.

Table 2. Digitized Rs/R_0 values from MQ sensors datasheets.

	Sensor gas MQ-135		Sensor gas MQ-8	
No.	PPM	Rs/Ro	PPM	Rs/Ro
1.	10.236	2.257	19.7211	8.200
2.	13.919	2.062	28.8955	5.069
3.	18.188	1.861	41.8909	3.134
4.	24.246	1.719	63.3641	1.846
5.	30.453	1.587	85.2856	1.198
6.	39.402	1.449	118.5039	0.758
7.	50.479	1.323	166.4172	0.458
8.	67.292	1.222	228.7953	0.290
9.	84.514	1.115	307.9493	0.188
10.	84.514	1.115	410.1127	0.122
11.	113.775	1.007	557.8838	0.074
12.	151.647	0.898	735.1220	0.045
13.	198.162	0.811	979.0016	0.027

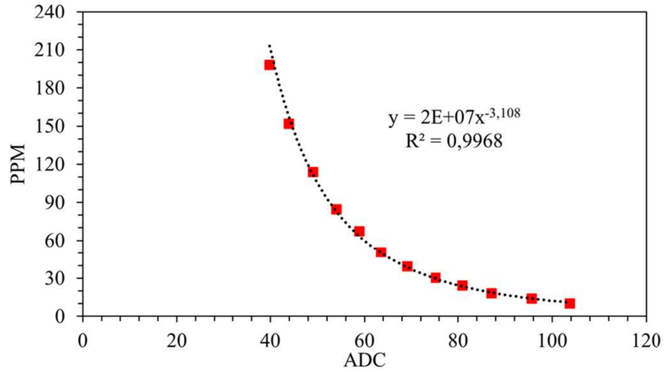

Figure 9. Comparison graph of PPM versus ADC values for the MQ-135 sensor datasheet.

Table 3. Calculation of PPM, Rs, V0, & ADC values for the MQ-135.

No.	PPM	R_s	V_0	ADC
1.	10.236	2.257	0.507031	103.73860
2.	13.919	2.062	0.467319	95.61354
3.	18.188	1.861	0.425644	87.08673
4.	24.246	1.719	0.395736	80.96768
5.	30.453	1.587	0.367582	75.20735
6.	39.402	1.449	0.337778	69.10938
7.	50.479	1.323	0.310228	63.47273
8.	67.292	1.222	0.287909	58.90614
9.	84.514	1.115	0.264030	54.02060
10.	84.514	1.115	0.264030	54.02060
11.	113.775	1.007	0.239682	49.03894
12.	151.647	0.898	0.214853	43.95894
13.	198.162	0.811	0.194849	39.86608

Table 4. Calculation of PPM, Rs, V0, & ADC values for the MQ-8.

No.	PPM	R_s	V_0	ADC
1.	19.7211	8.200	460.912	19.7211
2.	28.8955	5.069	344.228	28.8955
3.	41.8909	3.134	244.105	41.8909
4.	63.3641	1.846	159,417	63.3641
5.	85.2856	1.198	109.444	85.2856
6.	118.5039	0.758	72.0797	118.5039
7.	166.4172	0.458	44.8014	166.4172
8.	228.7953	0.290	28.8309	228.7953
9.	307.9493	0.188	18.8775	307.9493
10.	410.1127	0.122	12.3301	410.1127
11.	557.8838	0.074	7.51459	557.8838
12.	735.1220	0.045	4.58287	735.1220
13.	979.0016	0.027	2.75466	979.0016

Dioxide Detector and 29.81805% for the MQ-8 sensor error with a C-200 Pen-Type Water Quality Meter. The error results obtained in CO_2 measurements are quite low, this indicates that the MQ-135 sensor and the comparison tool have small differences in values and the comparison tool used has specifications that match the type of gas being measured, so the calibration process is carried out with a high level of accuracy. In H_2 measurements, the error value given is quite large, this is because the C-200 Pen-Type Water Quality Meter is designed more accurately to measure the concentration of dissolved hydrogen in water rather than to detect free hydrogen gas in the air, this will certainly cause a larger deviation in results and a low level of accuracy. Referring to the discussion in the paper written by [53], the sensor calibration method does not always require a very precise comparison measuring tool. Under certain conditions, such as limited funding or limited access to

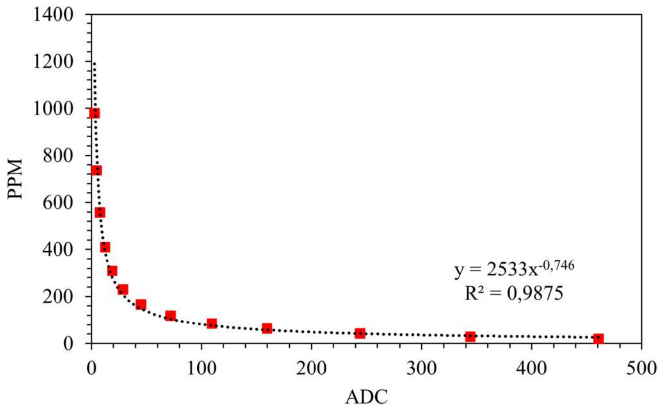

Figure 10. Comparison graph of PPM versus ADC values for the MQ-8 sensor datasheet.

Table 5. Result of measuring carbon dioxcide (CO_2).

No.	Sensor MQ-135 (PPM)	CO_2 Detector (PPM)	Error (%)
1.	451.2	448	0.71428
2.	455.5	452	0.77433
3.	450.2	458	1.70305
4.	467.2	458	2.00873
5.	458.4	453	1.19205
6.	451.2	460	1.91304
7.	448.8	457	1.79431
8.	451.3	453	0.37527
9.	471.2	462	1.99134
10	458.2	456	0.48245
		The mean error	1.29488

Table 6. Result of measuring hydrogen (H_2).

No.	Sensor MQ-8 (PPM)	H_2 Detector (PPM)	Error (%)
1.	0.055	0.075	26.66667
2.	0.032	0.045	28.88889
3.	0.039	0.055	29.09091
4.	0.042	0.067	37.31343
5.	0.058	0.067	13.43284
6.	0.059	0.045	31.11111
7.	0.032	0.055	41.81818
8.	0.032	0.056	42.85714
9.	0.055	0.067	17.91045
10	0.039	0.055	29.09091
		The mean error	29.81805

standard laboratory instruments, calibration can be performed by referring to technical data from the sensor datasheet or using available reference instruments in the field. However, this theoretical calibration method presents challenges, such as:

(1) Higher uncertainty: Data from the datasheet is usually generated under controlled laboratory conditions, so when used under different conditions, such as temperature, humidity, and pressure, it will produce different values.

(2) Limited resolution and sensitivity of reference instruments: As in the case of H_2 measurements, using instruments that are not specific for free hydrogen gas leads to significant error.

(3) Intersensor variability: Even sensors of the same type will have different response characteristics, so each sensor requires individual calibration.

While this theoretical calibration measurement presents many challenges, it can provide useful insights, especially if the calibration is performed using consistent procedures and the results are interpreted carefully. The results of CO_2 measurements which have an error of 2% indicate a good level of agreement, while for H_2, although the error is relatively large, the data can be used as a proof of concept or indicative monitoring stage, provided that the user understands its limitations and considers the possibility of improving this method in the future.

4. Conclusion

A datasheet-based calibration study has been carried out using the MQ-135 sensor and MQ-8 sensor to measure carbon dioxide and hydrogen using datasheet information. Based on the calculation results, a trendline of the power equation model has been obtained for the MQ-135 gas sensor and MQ-8 gas sensor respectively from the comparison of the *x*-axis (ADC) and *y*-axis (PPM), namely $y_{MQ-135} = 2 \times 10^7 x^{-3.108}$ with a value of $R^2_{MQ-135} = 0.9968$, and $y_{MQ-8} = 2533x^{-0.746}$ with a value of $R^2_{MQ-8} = 0.9875$. Based on the R^2 value or coefficient of determination for each sensor, it shows that the value is close to 1, so this shows that the trendline of the power equation model used matches the sensor datasheet. Based on the measurement results of the comparison tool, the average error value was 1.29488% for the MQ-135 and 29.81805% for the MQ-8. The error value of the MQ-135 is very low, indicating high compatibility with the comparison tool used, while the error value of the MQ-8 is high, which is influenced by the limitations of the comparison tool which is only designed to measure dissolved hydrogen in water, not free hydrogen in the air. This datasheet-based calibration method can be used as an alternative in conditions of limited funds or access to more practical calibration instruments, but the results must still be interpreted by considering the limitations of the comparison tool and the measurement conditions in the field.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

Author contributions

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Conceptualization (equal), Writing – original draft (equal), Writing – review & editing (equal)

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