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AN ANALYSIS OF EMISSIONS EXHAUST GAS ON 4-STROKE ENGINE BASED ON IOT GAS ANALYZER

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Abstract. According to the Air Quality Live Index (AQLI), Indonesia's air quality has continued to deteriorate in the last two decades, so Indonesia is officially ranked 17th as the country with the worst air quality in the world. This is due to the population explosion in Indonesia causing industrial activity to also increase. The high levels of exhaust emissions in vehicles, of course, requires the need for technology to measure vehicle exhaust gases to reduce the impact of air pollution. However, the procurement of exhaust emission test equipment is still expensive, so only certain class workshops have this tool. In addition, the reading results of the vehicle's OBD (On Board Diagnostic) system are only able to display the condition or reading value of the Lambda sensor because other gas sensor readings such as CO_2, HC, and CO cannot be displayed on the OBD reading results. The purpose of this study is to describe the design of the tool and the results of measuring CO and HC levels through the Blynk application. Research methods that use several gas sensors, such as MQ-7 and TGS-2602 (CO gas) and MQ-2 and TGS-2611 (HC gas), are then compared with the measurement results of a standard gas analyzer. The results showed that the MQ-7 value is close to the accuracy at 1000 rpm and 5000 rpm, namely 99.68% and 99.49%, while the level of accuracy at 3000 rpm is 99.37%. The TGS-2602 sensor at 1000 rpm only has the best accuracy and accuracy, namely 99.67% and 99.77%. The level of accuracy of the MQ-2 sensor has the best value at 1000 rpm rotation, which is 95.71% and the level of accuracy has the highest value at 7000 rpm rotation, which is 100%. For the level of accuracy of the TGS-2611 sensor, it has an accuracy level of 1000 rpm rotation of 94.65% and the level of accuracy of the sensor obtains very good values at 1000 rpm, 7000 rpm, and 9000 rpm rotation of 100%.

Keywords: CO gas, ESP32, Gas Analyzer, HC gas, sensors gas.

1. INTRODUCTION

According to the Air Quality Live Index (AQLI), Indonesia's air quality has continued to deteriorate in the last two decades, so Indonesia is officially ranked 17^{th} as the country with the worst air quality in the world [1]. This is due to the population explosion in Indonesia, causing industrial activities to also increase. The main factor that causes the air quality in Indonesia to decline is vehicle exhaust emissions [2][3].

The high levels of exhaust gas emissions in vehicles, of course, requires the need for technology to measure vehicle exhaust gases to reduce the impact of air pollution [4][5]. However, the procurement of exhaust emission test equipment is still expensive, so only certain class workshops have this tool and the cost of testing exhaust emissions is also expensive. In addition, the results of the vehicle's OBD (On Board Diagnostic) system readings are only able to display the condition or value of the Lambda sensor readings because other gas sensor readings such as CO_2, HC, and CO cannot be displayed on the OBD reading results. Exhaust gas emission test equipment or Exhaust Gas Analyzer can measure vehicle exhaust emission levels in the form of CO, HC, CO_2, O_2, NO_x, and Lambda [6].

Based on the description above, in this study, the author does a test for exhaust emission devices on vehicles with the Internet of Things (IoT) concept [7]. The purpose of this study is to describe the design to compare the results of measuring CO and HC levels through the Blynk application. This device consists of a set of gas sensors and a microcontroller named NodeMCU ESP32 which is equipped with displaying exhaust emission measurement data on Android via the Blynk application.

2. METHODS

The research design used the following model:

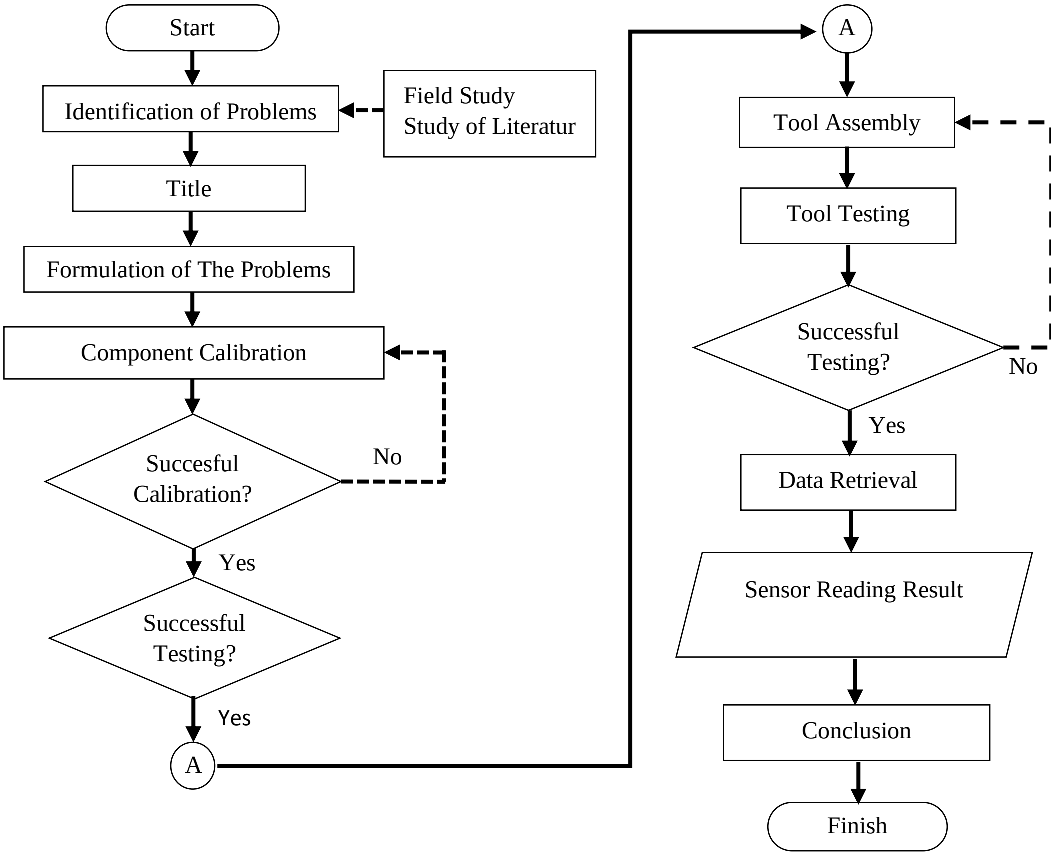

Figure 1. Implementation Flow Chart

The research used was an experimental study comparing CO gas sensors, namely MQ-7 with TGS-2442, and HC gas sensors, namely MQ-2 with TGS-2611, on variations in motorcycle RPM rotation on exhaust gas emissions. Experimental research is research conducted on data variables through the manipulation process stage by giving certain treatments to research subjects [8].

The first step that will be carried out is to perform the first calibration on the sensor through pre-heating and determining the ordinate and abscissa on the sensor datasheet graph. After obtaining the ppm value, the sensor will be compared with the ppm value of the Gas Analyzer on the same independent variable (the amount of RPM) to obtain the second calibration result. Data collection begins with preparing a test motorcycle that has been warmed up so that it is in an idle condition. The gas analyzer probe and all sensors are placed on the motorcycle exhaust and covered with cloth. This is so that the gas emissions that come out can be caught by all sensors and gas analyzers with the same gas. The ppm range for each sensor is different, such as for detecting CO gas, namely MQ7 at 20-2.000 ppm [9][10] and TGS2602 having 1-30 ppm [11][12], while for detecting HC gas, MQ2 has a range of 300-10.000 ppm [13][14] and TGS2611 at 500-10.000 ppm [15][16]. The final result of all data retrieval can be seen through a gadget with IoT Remote software that has been installed and programmed with sensors.

Data was collected by calibrating each sensor by determining the ordinate and abscissa values from the sensitivity graph based on the MQ2, MQ7, TGS2606, and TGS2611 sensor datasheets. This experiment begins by determining the value of room air (Ro) through programming in the Arduino IDE. ESP32 has a 12-bit analog pin so it can convert analog data to 4095, meaning that the value 0 indicates a voltage of 0 volts and the value 4095 represents a voltage of 5 volts. The purpose of this is to do this as a pre-heating stage on the sensor for 1 hour with the following formula:

$$VRL = \frac{V_{in}}{ADC} \dots\dots\dots\dots\dots\dots\dots (1)$$

$$R_s = \left(\frac{V_{in}}{VRL} - 1\right) RL \dots\dots\dots (2)$$

$$R_o = \frac{R_s}{9.6} \dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

Where:
VRL = Output voltage
V_{in} = Input voltage
ADC = Analog value
RL = Load resistance
R_o = Resistance of sensor
R_s = Resistance in different gases

Furthermore, the sensor will get the ppm value through the intersection of the sensor datasheet graph with the following formula [17]:

$$m = \frac{log(y_2) - log(y_1)}{log(x_2) - log(x_1)} \dots\dots\dots\dots (4)$$

$$b = log(y) - m\, log\,(x) \dots\dots\dots\dots (5)$$

$$ppm = \frac{log_{10}(ratio) - b}{m} \dots\dots\dots\dots (6)$$

3. RESULTS AND DISCUSSION

In detail, the hardware design consists of ESP32 components, Sensors MQ2, MQ7, TGS2602, TGS2611, I2C, LCD, DHT11, and other indicators, namely LEDs. The source used is sourced from DC voltage. Prior to compile coding, all sensors will be pre-heated first in order to obtain air conditions (Ro) as a condition for carrying out the first calibration with the sensor datasheet.

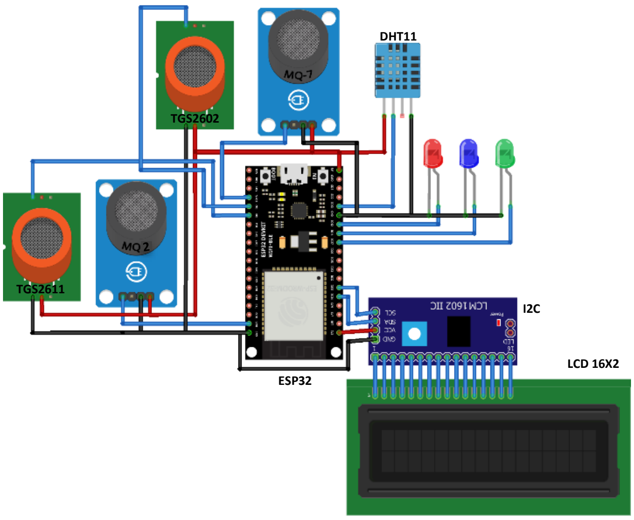

Figure 2. Software Design

Software design for ESP32 aims to embed system work algorithms with the C++ sketch language to program ESP32. The software used for coding is the Arduino IDE. When the coding process has been compiled and then uploaded to ESP32 using a micro USB connection, it will be embedded directly and stored in ESP32. In general, the performance of the program works by reading the parameters on the gas sensor (Pin D22, Pin D15, Pin D2, and Pin 4). If the sensor detects CO and HC gases, the system will display sensor values on the LCD and the gadget. Changes in these values will be monitored continuously when all sensors are active.

Before the sensor will be tested, the first calibration is carried out with a graph of the sensitivity of the sensor datasheet. The goal is to get an accurate ppm value according to the sensor datasheet. The reading results are then calculated and the ppm value is obtained from the sensitivity graph of the sensor datasheet in the Arduino IDE program. The gas analyzer used is QRO-401.

Table 1. First Calibration Results

RPM Rotation	Standard Gas Analyzer		IoT-Based Gas Analyzer			
			MQ Sensor Type		TGS Sensor Type	
	CO(%)	HC(ppm)	CO(%)	HC(ppm)	CO(%)	HC(ppm)
1000	4.3	599.5	5.91	633	6.35	593
3000	4.75	445	5.5	510.5	5.515	455.5
5000	5.44	162	6.41	336	6.265	199
7000	5.225	143.5	5.75	301	6.065	141.5
9000	5.97	128	6	280	6.98	129

After the output results are obtained in the form of ppm on all sensors and gas analyzers, then a linear regression comparison is performed for the next calibration so that the output value is obtained with accurate results. The results of this comparison will later be in the form of a formula which will later be combined with the previous coding and compiled coding to the Arduino IDE.

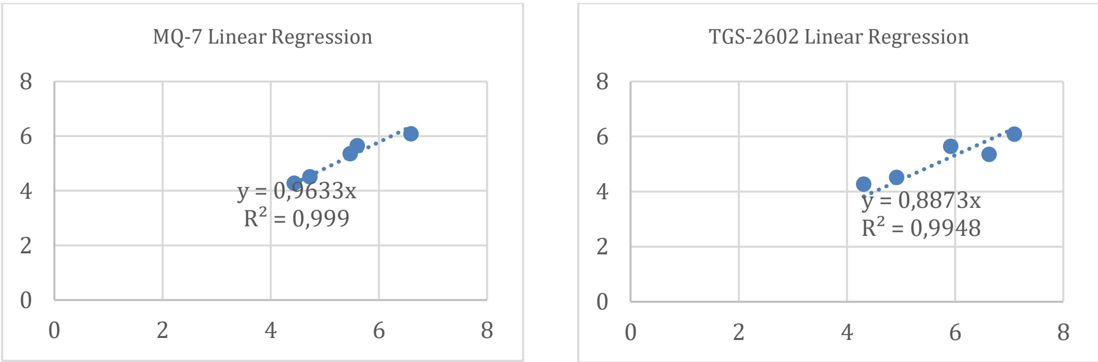

Figure 3. Linear Regression of CO Gas

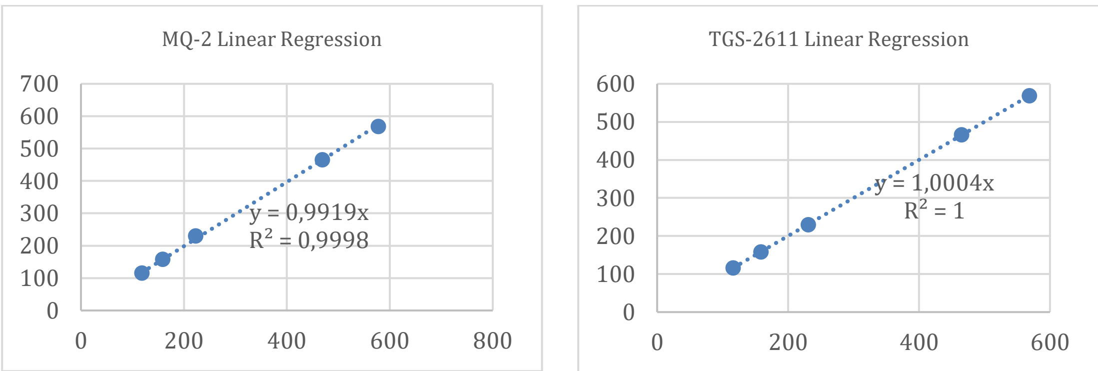

Figure 4. Linear Regression of HC Gas

The gas sensor calibrations in Fig. 3 (a,b) and Fig. 4 (a,b) show the CO and HC gas sensor readings with a standard gas analyzer whose values are known. Based on the data obtained for linear regression sensor MQ-7 equation Y = 09633x with a value of R2 = 0.999, linear regression sensor TGS-2602 equation Y = 0.8873x with a value of R2 = 0.9948, linear regression sensor MQ-2 equation Y = 0.9919x with a value of R2 = 0.9998, linear regression sensor TGS-2611 equation Y = 1.0004x with a value of R2 = 1 which is then used as a gas sensor function (calibration).

Based on the results of the regression analysis related to the relationship between the difference in CO and HC readings from the sensor and the gas analyzer. This shows that the curve forms a pattern so that the regression model of the curve is normal and normally distributed. This is because the plots of the data are spread out and follow a normal distribution pattern.

Table 2. Second Calibration Results

RPM Rotation	Standard Gas Analyzer		IoT-Based Gas Analyzer			
			MQ Sensor Type		TGS Sensor Type	
	CO(%)	HC(ppm)	CO(%)	CO(%)	HC(ppm)	HC(ppm)
1000	4.275	568.5	4.43	577.5	4.31	568.5
3000	4.51	466	4.72	469	4.92	465
5000	5.645	230	5.6	222.5	5.915	231
7000	5.355	158.5	5.47	158.5	6.63	158.5
9000	6.085	116	6.59	118	7.095	116

In the graph above (Fig. 4) the results of the TGS-2611 sensor readings compared to a standard gas analyzer are close to perfect accuracy for HC gas. The 2000-3000 rpm rotation has a difference of only 1 ppm. When compared to the MQ-2, it has a difference with a range that is quite far as the validity of the measuring instrument. Referring to the Regulation of the Minister of Environment the CO value limit does not exceed 4.5% and HC 1200 ppm [18][19]. This shows that the linear regression equation as a calibration function can improve the performance of each sensor to be good. The validation results from the linear regression analysis on the sensor can give good results with an accuracy level of 99.51% and an accuracy of 98.89% [20].

In testing the performance of a gas sensor measuring instrument obtained from the results of the 2nd reading. Then the level of accuracy of the entire test gas sensor is obtained.

Table 3. CO and HC Value from Gas Analyzer

CO Value on Gas Analyzer	4.3	4.75	5.44	5.225	6.1
HC Value on Gas Analyzer	568.5	466	230	158.5	116

Table 4. The Accuracy and Precision of the MQ-7 Sensor

Rotation (RPM)	1000	3000	5000	7000	9000
Experiment 1	4.42	4.8	5.58	5.4	6.66
Experiment 2	4.44	4.64	5.62	5.54	6.52
Average	4.43	4.72	5.6	5.47	6.59
St. Deviation	0.01	0.11	0.03	0.10	0.10
Accuracy (%)	99.68	97.60	99.49	98.19	98.50
Precision (%)	96.98	99.37	97.06	95.31	91.97

Table 5. The Accuracy and Precision of the TGS-2602 Sensor

Rotation (RPM)	1000	3000	5000	7000	9000
Experiment 1	4.3	4.86	5.55	6.72	6.97
Experiment 2	4.32	4.98	6.28	6.54	7.22
Average	4.31	4.92	5.915	6.63	7.095
St. Deviation	0.01	0.08	0.52	0.13	0.18
Accuracy (%)	99.67	98.28	91.27	98.08	97.51
Precision (%)	99.77	96.42	91.27	73.11	83.69

Table 6. The Accuracy and Precision of the MQ-2 Sensor

Rotation (RPM)	1000	3000	5000	7000	9000
Experiment 1	560	512	260	129	114
Experiment 2	595	426	185	188	122
Average	577.5	469	222.5	158.5	118
St. Deviation	24.75	60.81	53.03	41.72	5.66
Accuracy (%)	95.71	87.03	76.16	73.68	95.21
Precision (%)	98.42	99.36	96.74	100.00	98.28

Table 7. The Accuracy and Precision of the TGS-2611 Sensor

Rotation (RPM)	1000	3000	5000	7000	9000
Experiment 1	547	510	280	129	112
Experiment 2	590	420	182	188	120
Average	568.5	465	231	158.5	116
St. Deviation	30.41	63.64	69.30	41.72	5.66
Accuracy (%)	94.65	86.31	70.00	73.68	95.12
Precision (%)	100.00	99.79	99.57	100.00	100.00

In this test, the value obtained from the precision and accuracy of measuring instruments for several gas sensors (X) with a standard gas analyzer (Y). The MQ-7 and TGS-2602 sensors have a level of accuracy and accuracy that is still not accurate enough for each rotation (rpm). In MQ-7, the values that are close to the accuracy at 1000 rpm and 5000 rpm are 99.68% and 99.49%, while the level of accuracy at 3000 rpm rotation is close to the accuracy of 99.37%. This is influenced by the sensor material which has low conductivity so that the heater component as sensitivity to the sensor becomes less precise. For the TGS-2602 sensor, only at 1000 rpm has the accuracy and accuracy of 99.67% and 99.77%. Referring to the TGS-2606 sensor datasheet, this type of sensor has a low sensitivity range of 1-30 rpm so that in the first round it can work properly according to gas analyzer standards.

In the HC gas test, the level of accuracy and accuracy of the MQ-2 sensor has a significant difference. The level of accuracy of the MQ-2 sensor has the best value at 1000 rpm, which is 95.71% and the lowest value is 73.68%. And for the level of accuracy, it has a high accuracy value that is even the same as the standard gas analyzer value, at 7000 rpm rotation which is 100%, and followed by 3000 rpm rotation of 99.36%. For the level of accuracy, the TGS-2602 sensor has a low level of accuracy, with the highest value at 1000 rpm of 94.65%. However, at the level of accuracy, the sensor obtained a very good value compared to other sensors, namely at 1000 rpm, 7000 rpm, and 9000 rpm at 100%, followed by 3000 rpm rotation, 5000 rpm at 99.79%, and 99.57%.

The standard gas analyzer value calculation is the average of 2 tests. When compared to the average sensor with a standard gas analyzer, it is actually not much different. So, the accuracy level deviates far from the standard gas analyzer value. However, the accuracy of the designed measuring instrument can be a reference in determining the standard measuring instrument by knowing the ability of the measuring instrument to read measurements that can be close to the actual size value.

4. CONCLUSION

In the first calibration, it was found that the TGS-2602 sensor value could not approach the CO value with a standard gas analyzer. This is influenced by the sensitivity of the TGS-2602 sensor which has a low range of 1-30 ppm. The MQ-2 sensor in detecting HC gas is still far from the standard gas analyzer value. Compared to the TGS-2611 sensor, the HC value is almost as accurate as that of a standard gas analyzer. This is because the MQ-2 sensor datasheet has a sensitivity range of 300-10,000 ppm, while the TGS-2611 has a range of 10,000-250,000 ppm. Even though the CO value on MQ-2 is obtained according to the range, this is also influenced by the material factors of each sensor. Based on the data obtained for linear regression sensor MQ-7 equation Y = 09633x with a value of R2 = 0.999, linear regression sensor TGS-2602 equation Y = 0.8873x with a value of R2 = 0.9948, linear regression sensor MQ-2 equation Y = 0.9919x with a value of R2 = 0.9998, linear regression sensor TGS-2611 equation Y = 1.0004x with a value of R2 = 1 which is then used as a gas sensor function (calibration). HC gas testing, the level of accuracy and accuracy of the MQ-2 sensor has a significant difference. The level of accuracy of the MQ-2 sensor has the best value at 1000 rpm, which is 95.71% and the lowest value is 73.68%. And for the level of accuracy, it has a high accuracy value that is even the same as the standard gas analyzer value, at 7000 rpm rotation which is 100% and followed by 3000 rpm rotation of 99.36%. For the level of accuracy the TGS-2602 sensor has a low level of accuracy, with the highest value at 1000 rpm of 94.65%. However, at the level of accuracy the sensor obtained a very good value compared to other sensors, namely at 1000 rpm, 7000 rpm and 9000 rpm at 100%, and followed by 3000 rpm rotation, 5000 rpm at 99.79% and 99.57%. This IoT gas analyzer has several weaknesses that can be developed in further research, such as sensor sensitivity reassembled with material changes and heater sensors so that when the preheating time is faster and needs to be done regarding repeatability for consistency the sensor when used regularly.

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