Journal of Information Technology and Computer Science
Volume 9, Number 1, April 2024, pp. 1-11
Journal Homepage: www.jitecs.ub.ac.id

Simple and Cost-Effective Detection of Carbon Monoxide Gas

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Received 18 August 2023; accepted 26 March 2024

Abstract. In several major cities throughout Indonesia, the air pollution represents a significant issue. The escalation of motorized vehicle usage yields increased concentrations of carbon monoxide gas, as one of the primary sources of gas pollution. This study introduced a tool designed and implemented for detecting levels of carbon monoxide gas and providing accurate indications. The tool used an MQ-7 gas sensor in combination with a dot matrix display for this purpose. The detection apparatus was comprised of an IC 74HC595, an ATMEGA16 microcontroller, a BC557 PNP transistor, and a LED dot matrix. The ATMEGA16 microcontroller served as the primary control device of the system. It received input signals from the MQ-7 gas sensor and subsequently converted them into digital format for display on the dot matrix. The IC 74HC595 and transistor BC557 were utilized as the column controller and line controller, respectively, in the 5x8 LED dot matrix. The gas level measurement at 0 cm exhibited the lowest error of approximately 0.6 %, measuring 300 ppm CO gas levels. On the other hand, at 10 cm, the result showed approximately an error of 6.7 % for a CO gas level of 200 ppm.

Keywords: carbon monoxide gas, MQ-7 sensor, ATMEGA, dot matrix display, gas detector

1 Introduction

The problem of air pollution in Indonesia is influenced by several causes, one of which is the increasing number of motorcycles. The DKI Jakarta Central Statistics Agency showed the number of vehicles has increased to more than 20 million in 2020 for all types of motorized vehicles, having a big effect on increasing air pollution. The pollution has a negative impact on human health due to pollutants released from motorcycles´ exhausts. In 2019 several big cities in Indonesia showed a significant report of PM10 and PM2.5 in air quality monitoring [1], e.g. 42 $\mu g/m^3$ in Pontianak and 57 $\mu g/m^3$ in Pekanbaru due to forest and field fires. A report in 2020 presented a passive sampler method used in AQSM (Air Quality Monitoring System) for those cities and it showed a decrease of around 15 % in average compared to the data in 2019. PM or particulate matter may be derived from various pollutant gases such as SO_2, NO_2, CO and others. Carbon monoxide (CO) gas cannot be recognized physically due to its odorless, tasteless, and colorless, making it difficult to anticipate the dangers of its toxic [2]. To reduce the level of air pollution due to the high concentration of carbon monoxide gas some materials and technical recommendations were provided in the form of monitoring and providing public information on air quality [3].

Air pollution standards in Indonesia have been regulated by the Decree of the State Minister of the Environment concerning the air pollution standard index. The range of 0-50 ppm is categorized as good, since the level of air quality has no effect on the health of humans, animals, plants, buildings, or aesthetic value. The range of 51-100 ppm air levels is categorized as moderate. The level of air quality in this range has no effect on human or animal health, but it affects sensitive plants and aesthetic values. The unhealthy category is in the range of 101-199 ppm, which is detrimental to humans or a group of sensitive animals or it can cause damage to plants and aesthetic values. The 200-299 ppm range, which is categorized as very unhealthy, air quality levels endanger health in several exposed segments of the population. The range of more than 300 ppm is categorized as a hazard, this can seriously harm the health of the population [2], [4].

Reviews on several sensors' materials, e.g. electrochemical and semiconductor for detecting gases such as methane, CO_X or ammonia had been reported in [3] , and on carbon nanomaterials-based gas sensors was described in [5]. Meanwhile the characterization of materials used for NO_X gas sensor had been explained in [6], and metal-oxide-based CO gas sensor had been presented in [7] . In [8] a system to detect gas emission of automotive vehicles and monitoring the CO gas based on microcontroller [9] had been developed. Newton et al. developed a microcontroller-based CO detection using TGS2442, completed with GPS technology for mapping system [10]. Research related to the implementation of the moving message display system using a microcontroller had been carried out in [11].

This research is conducted to make a tool having the ability to detect air quality based on carbon monoxide gas levels using ATMEGA16 microcontroller as a regulating part, and an LED dot matrix as the display of the tool. ATMEGA16 was not only a cost effective, but also a low power microcontroller which is one of the AVR types [12], even though Wi-Fi was not included it was easy to program. The ATMEGA was able to embed for different applications, e.g. automotive [13], to control robot gamelan music [14], to realize an IoT based smart dustbin [15] or smart home [16], [17], to implement monitoring systems in beverage industry [18], [19], and to prevent the leakage gases [20]–[22].

Carbon monoxide gas levels from this tool are detected using the MQ-7 gas sensor, with a measurement range of 20 ppm to 2000 ppm, and the display used a 5x8 LED dot matrix with the microcontroller. This tool could be applied indoors or outdoors.

This paper is organized as follows. The introduction where the background situation of air pollution in Indonesia caused mostly by motorcycles being explained. The method is described in the second section, i.e. design of hardware components: sensor circuit, column and row of the dot matrix controls, and the microcontroller. Followed by a design of the software. The results and discussions would be presented in the third section, and they were concluded in the fourth section.

2 Methods

2.1 Designing of MQ-7 sensor circuit

Figure 1 shows the flowchart of process in the MQ-7 gas sensor, where at the beginning around 100 ppm of gas input is given to the sensor. After that, measurement of the load voltage V_{RL} is performed. This voltage is used to obtain the sensor resistance R_S. and then the resistance ration value of R_S/R_O would be used to get the R_O or the sensor resistance at 100 ppm CO in the clean air.

Results of the calculation of R_S based on V_{RL} value were summarized in Table 1 at different gas levels. Measurement tests of gas level using the tool were done and compared with the Stargas 898, at 0 cm (i.e. close to the vehicle gas output) and 10 cm.

2.2 Designing of column and row of LED dot matrix controls

The column control circuit is used to determine which LEDs are activated in the column series of the dot matrix. This circuit used a BJT PNP BC557 transistor with electrical specifications including V_{EB}= 0.8 V, = 110, V_{CEO}= -65 V (maximum). The transistor is used as a switch to determine the active LED in the column row. By using Kirchoff's Voltage Law, the value of the base resistor used could be determined based on Fig. 2.

Since the total collector resistance R_C equal to 200 Ω was uncommon in the market, we used the value of 220 Ω. Based on the loop 2 calculation we had a collector current of I_C using the following equation, where V_{EE} was the voltage common emitter.

$$I_C = \frac{V_{EE}}{R_C} \tag{1}$$

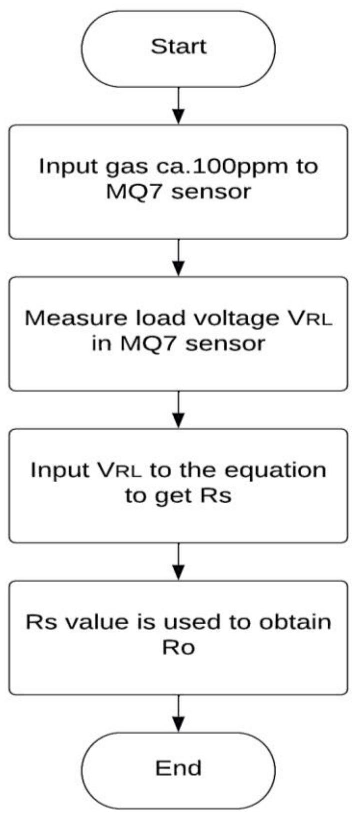

Figure 1. Flowchart to look for R_0 of MQ-7 gas sensor

Table 1. Calculated data for Load Voltage V_{RL} on sensors

Gas concentration (ppm)	R_S (Ω)	V_{RL}(V)
20	160765.025	0.2928
150	128612.02	0.36
200	96459.015	0.469
250	888420.7	0.508
300	77167.212	0.573
350	69128.96	0.631

Based on the results of the row (line) control circuit design, the base resistance value of 3521.127, collector resistance of 220, and collector voltage (V_C) of 5 V were obtained. The resistance value of 3521.127 Ω could be replaced with a resistor of 3.9 kΩ. The character that would be displayed on the dot matrix required a control circuit for the matrix column. The column control circuit is used to determine which columns are activated to form the created character. The row (line) control circuit had an input in the form of serial data and an output in the form of parallel data. The component device of the column control circuit on the LED dot matrix was IC 74HC595.

Testing of the control circuit of the matrix column is carried out to determine the performance of the circuit when the given data is input from the microcontroller. To form a character, a series of row controls is required to form a character from a series of columns. The characters that would be displayed activated all odd columns on the matrix and turned off all even columns on the matrix.

2.3 Designing of the ATMEGA16 circuit

The ATMEGA16 microcontroller circuit used an external oscillator in the form of a 12 MHz crystal with two 22 pF capacitors, a 10 kΩ pull-up resistor and a 10 µF capacitor for reset, and an LED with a 330 resistor as an indicator of the ATMEGA16 microcontroller. For the input voltage from the microcontroller circuit used a diode as a safety input voltage and IC 7805 regulator to reduce the voltage from the power supply by 9 VDC to + 5 VDC.

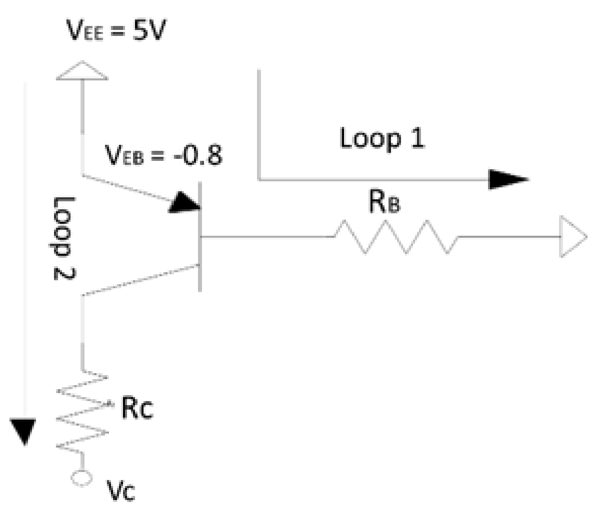

Figure 2. Row (line) control circuit

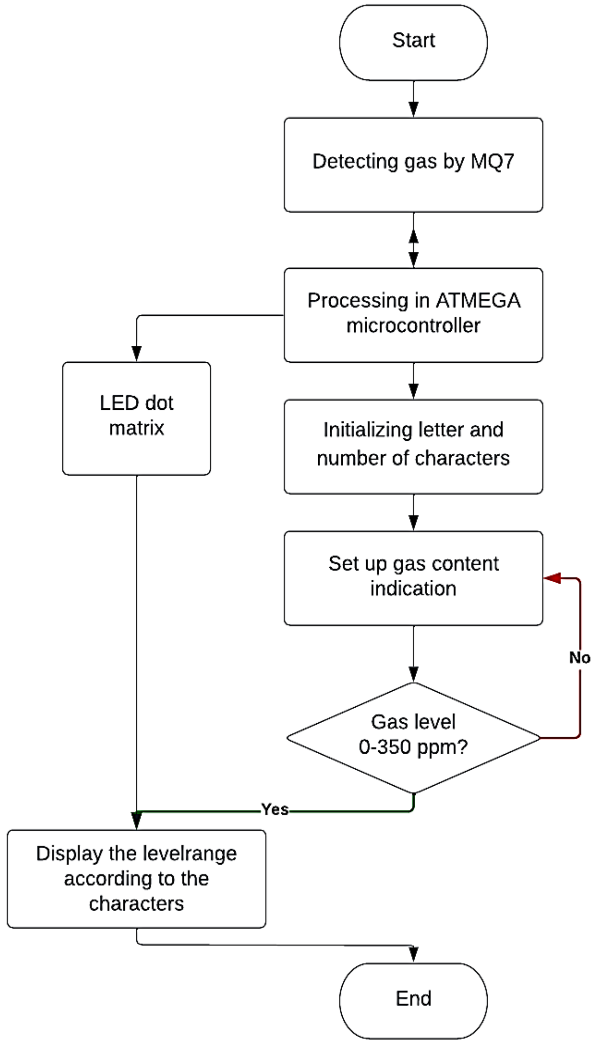

Figure 3. Flowchart software design to display the gas level indication

2.4 Designing of the software

The program in the software is used as a controller on microcontroller hardware. The process of the program in the software started by detecting the gas levels detected by the MQ-7 CO gas sensor, shown in Fig. 3. Data from gas levels that have been detected by the sensor is processed on the microcontroller. Previously, the microcontroller initialized the characters of letters and numbers used to display information on gas levels and their indications into the LED matrix. Sensor data processed by the microcontroller is displayed into the LED as well as an indication of the quality of the gas.

The program in the software started with the initialization of letters and numbers of characters. Initialized numeric characters included 0.1,2,3,4,5,6,7,8,9 and initialized letter characters included A, D, E, G, H, I, L, M, N, O, R, T, U, Y. After initializing the characters of letters and numbers, then set up the indication of the gas content that has been determined. If the CO gas content was less than 50 ppm, the indication value showed "GOOD". If the gas level was between 51 ppm to 100 ppm, the indication was "MEDIUM". If the value of CO gas was between 101 ppm to 299 ppm, then the indication showed “UNHEALTHY”. If the gas level was more than 299 ppm, then the indication displayed “DANGER”. The indication value of the gas content is shown in the dot matrix.

3 Results and Discussion

3.1 MQ-7 sensor test results

Sensor circuit test data is used to determine the performance of the sensor. Changes in the sensor are influenced by the level of carbon monoxide gas detected by the sensor. Changes in gas levels detected could affect the load resistance of the sensor. The greater the gas content detected by the sensor, the smaller the load resistance of the sensor. Based on the data in Table 2, the linearity of the sensor of 2.94 % was obtained showing that the sensor worked well.

3.2 The ATMEGA16

Testing of the ATMEGA16 microcontroller circuit aimed to determine the performance of each port of the microcontroller. The port of the microcontroller is used as input or output of the system tool. Testing the microcontroller circuit is carried out by entering a program that has been previously designed into the microcontroller by downloading it using ProgISP software, and USB-ASP hardware as an interface between the ProgISP software and the microcontroller circuit. Testing of the microcontroller circuit required a simple LED circuit.

The sensor sensitivity can be summarized in Table 3. The MQ-7 sensor datasheet showed the minimum resolution value that could be read by the sensor at 20 ppm with a voltage of 0.1 V. The voltage value of the minimum resolution is assumed to be 5 V. Based on the test, the characteristics of the MQ-7 was linear, and it had an average sensitivity of 0.0012, an average percentage of error measurement or an accuracy of 2.619 %, and it had a precision level of 29.07 %.

Table 2. Sensor circuit test results

CO Gas (ppm)	V_{RL} design (V)	V_{RL} test-1 (V)	V_{RL} test-2 (V)	V_{RL} test-3 (V)	V_{RL} average (V)
50	0.252	0.26	0.26	0.25	0.2566
150	0.360	0.35	0.36	0.35	0.3533
200	0.469	0.45	0.46	0.45	0.4533
250	0.508	0.55	0.52	0.51	0.5266
300	0.573	0.56	0.56	0.57	0.5633
350	0.631	0.60	0.61	0.62	0.61

Table 3. MQ-7 sensor sensitivity

CO gas level (ppm)	Sensitivity value ($\frac{V}{PPM}$)
150 - 200	0.002
200 - 250	0.0014
250 -300	0.0007
300 - 350	0.0009
Average	0.0012

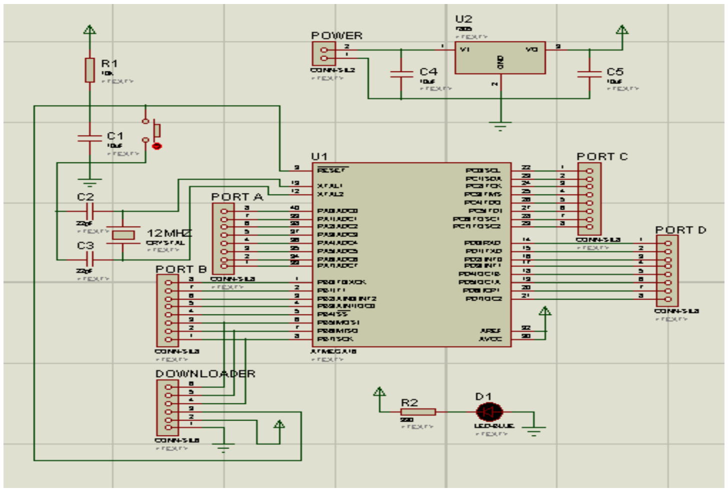

Figure 4. ATMEGA16 circuit

Table 4. Result of testing of collector voltage row (line) control circuit

	Input Signal	Collector Voltage (Design)	Test Result
Transistor 1			0 V
Transistor 2			0 V
Transistor 3			0 V
Transistor 4	5 V	0 V	0 V
Transistor 5			0 V
Transistor 6			0 V
Transistor 7			0 V
Transistor 8			0 V
Transistor 1			4.89 V
Transistor 2			4.89 V
Transistor 3			4.87 V
Transistor 4	0 V	5 V	4.90 V
Transistor 5			4.90 V
Transistor 6			4.86 V
Transistor 7			4.86 V
Transistor 8			4.86 V

PORT B ATMEGA16 covered pin 1 to pin 8, shown in Fig. 4. The PORT had several features i.e. Timer 0-1, Interrupt, SS, MOSI, MISO, and SCK. PORT D included pins 14 to 20 having several features i.e. TX, RX, INT 0-1, OC1B, OC1A, and ICP1. PORT C included pins 21 to 29 having features including: OC2, SCL, SDA, TCK, TMS, TDO, TDI, TOSC2, and TOSC1. While PORT A included pins 33 to 40 with overall features are used as ADC. All PORTs on ATMEGA16 could be used as Input/Output. All pins in ATMEGA16 worked properly.

3.3 Test of row (line) and column controls

The row or line control circuit is used to determine the active row in the LED dot matrix. Row (line) control circuit testing is performed to get the performance of the circuit. Line control circuit testing is done by giving a high signal condition "1" at the base point of the PNP transistor. Furthermore, by giving a low signal condition "0" at the base point of the PNP transistor. The controller of the high and low signals used the microcontroller circuit. Line control circuit testing is taken on each transistor contained in the circuit. The line control circuit had a good performance if the collector voltage of the circuit was around 5 V according to the design discussed in the previous chapter. Table 4 shows the measurement results. Based on the results in Table 4, the line control circuit worked very well, since the minimum voltage required was 4.5 V if the input signal was "Low". The lowest voltage of 4.86 V was detected as the input signal showed "Low".

The column control circuit is used to determine the active column in the LED matrix. The measurement results of 35 columns were taken, where each odd column had an active state and even column showed off state (Fig. 5 showed the prototype of 7 arrays @5 dot matrices). The active and off condition were represented by 4.9 V and 0 V, respectively. The ATMEGA16 circuit is used as the controller, while the LED line control circuit is used to determine the active LED line which is commanded directly from the program on the ATMEGA16 microcontroller. The column control circuit is used to determine the column shift in the LED dot matrix.

Table 5. Tool test results at 0 cm

Value of Stargas898	Measurement Test (ppm)			Test Average (ppm)	Error Average (%)
	1	2	3		
50 ppm	45	65	60	56.66	13.33
120 ppm	123	127	125	125	4.16
150 ppm	155	168	152	158.33	5.55
200 ppm	210	220	210	213.33	6.66
220 ppm	235	240	230	235	6.81
250 ppm	240	260	240	246.66	4
300 ppm	295	320	290	301.66	0.55
350 ppm	340	370	360	356.66	1.9

Figure 5. The gas detector prototype

Table 6. Tool test results at 10 cm

Value of Stargas898	Measurement Test (ppm)			Test Average (ppm)	Error Average (%)
	1	2	3		
50 ppm	70	60	75	68.33	36.66
120 ppm	127	130	132	129.66	8.05
150 ppm	168	170	160	166	10.66
200 ppm	210	210	220	213.33	6.66
220 ppm	230	240	235	235	6.81
250 ppm	270	280	270	273.33	9.33
300 ppm	320	330	330	326.66	8.88
350 ppm	370	390	380	380	8.57

p-ISSN: 2540-9433; e-ISSN: 2540-9824

Table 7. Carbon Monoxide gas indication data

CO gas level	Indicator display
45 ppm	Medium
123 ppm	Unhealthy
155 ppm	Unhealthy
210 ppm	Unhealthy
235 ppm	Unhealthy
240 ppm	Unhealthy
295 ppm	Dangerous
340 ppm	Dangerous

Finally, the overall testing is accomplished by combining all the modules into one tool system and entering the main program on the microcontroller. The test is carried out several times at different distances. The first test is taken at 0 cm (results summarized in Table 5), and the second test was at 10 cm (results summarized in Table 6). The test began by giving gas input to the calibration tool, namely the Stargas 898 and to the tool being made (see Fig. 5). The test of one data variable is carried out for ± 30 seconds to reach the idle time of the test vehicle. After investigating the gas value listed on the Stargas 898 and the tool, then the two gas levels are compared to find out the errors that occurred in the designed tool.

Results as the overall test performed at 0 cm, showed errors of 4 %, 0.55 % and 1.9 % for detection of 250 ppm, 300 ppm, and 350 ppm CO gas level, respectively. However, three times tests at 50 ppm revealed an error of 13.3 %. Table 7 shows data of the CO gas levels along with the indications displayed on the LED dot matrix. It showed the ‘unhealthy’ status at the detection of gas level of more than 120 up to 240 ppm. The proposed gas detector employed the ATMEGA 16 microcontroller as its primary component, selected for its comparatively lower cost despite its relatively less advanced features, when compared to other available microcontrollers. However, the subsequent test results demonstrated the detector's excellent, as indicated by the minimal error rate of only 4.16 % at 0 cm and 8.05 % at 10 cm, specifically when measuring a concentration of 120 ppm of CO gas.

4 Conclusion

We developed the carbon monoxide gas quality indicator tool with an LED matrix display. The tool was completed with an MQ-7 sensor, the ATMEGA16 microcontroller, IC 74HC595, BC557 PNP transistor, and a 5x8 LED dot matrix. The ATMEGA16 microcontroller was used as a control device of the system. The ATMEGA16 microcontroller received the input signal from the MQ-7 gas sensor and converted it into digital form to be displayed into the LED matrix. IC 74HC595 was used as a column controller in the LED matrix. Transistor BC557 was used as a line controller in the LED matrix.

Sensor field testing in this study had slight differences from the design. The error value in the sensor test was based on the comparison of the value in the design of the sensor load voltage (V_{RL}) to the value of the measurement. Testing of the line circuit when the input voltage on the base was 5 V, showed an average error of 0 %, meanwhile when the input voltage at the base was 0 V there was an average error of 2.425 %. Overall system testing was performed by comparing the values listed on the display with the values displayed on the Stargas 898 tool, and it was taken at 0 cm and 10 cm. At 0 cm the highest error value of 13.33 % was obtained at 50 ppm, and the lowest error of 0.55 % at 300 ppm gas level. However, at 10 cm the lowest error of 6.7 % was recorded at a gas level of 200 ppm. For future work, to reduce the average error especially at low gas level (less than 100 ppm) the calibration test would be required before applying other methods in the detector system.

Acknowledgments. We thank Mr. Julius St. for his support during the project work.

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