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Microcontroller-based air quality monitoring design using mamdani fuzzy method

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ABSTRACT

Hazardous gases such as carbon monoxide (CO) and sulfur dioxide (SO_2) not only emerge in the outdoor environment but also inside the house or factory which will endanger the occupants or workers. The detection devices are mainly found on public roads since detected gas mostly consists of CO and SO_2. The design of air quality monitoring devices is proposed with applied sensors such as TGS2201 and MQ136. The device, when activated, will detect the gas components in the room. The results of the detection will be displayed in the value of gas concentration and quality. If the concentration exceeds the specified threshold, the fan will act to neutralize the contained air. Fuzzy logic is applied with the membership function using the Sugeno model. The test is applied in the box with maximum air pollution of 80 ppm according to the motor vehicle gas, and out of the box at a public road with maximum air pollution of 51 ppm. Each method has the differences of 29 ppm.

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1. INTRODUCTION

Air pollution results from incomplete combustion, in which the process produces harmful gases which are often found to be carbon monoxide (CO) and sulfur dioxide (SO_2). It is very difficult indeed to reduce the level of production of these gases. This is because these two types of gas are produced from exhaust emissions of motor vehicles and industry [1]–[3].

Air pollution is defined as a decrease in air quality so that the quality of the air decreases when it is used and finally it cannot be used as it should according to its function. Air pollution is a problem that worries many people lately. The impact of air pollution is very dangerous for health. Various efforts have been made by the government to overcome this problem [4]–[11].

Currently, the tool for monitoring air quality is the air pollutant standard index (APSI) board. This tool is very expensive and the method of notification to the surrounding community is not timely. The APSI which is reported to the public applies 24 hours in the future, i.e. the notification is only once a day by taking the average value of the measurements [11]–[24]. The purpose of this research is to design a tool for continuous monitoring and early warning of air pollution levels using the fuzzy logic method with TGS2201 and MQ136. This tool is monitored via personal computer which later can be monitored continuously and can be implemented in areas densely packed with motorized vehicles [25]–[28].

2. SYSTEM DESIGN

To implement the system, the required hardware and software are displayed in Figure 1. The microcontroller ATMega32 is applied as the main controller. For the control algorithm code with such the microcontroller, CodeVision CVAVR IDE is applied.

ATMega32 from Figure 1 is applied as the main controller to maintain the process from input to output. The input in the system included MQ-136 as the SO_2 sensor and TGS 2201 as the CO gas. DC motor is applied to drive the exhaust fan, and also LCD to display sensor reading results. MAX232 is applied to form a communication with PC.

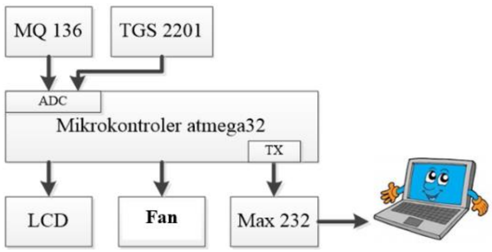


Figure 1. Overall system design

2.1. Mechanical design

The mechanical design of the air quality monitoring includes control box, fan, and sensors. Control Box consists of ATMega32, LCD, and power supply to power microcontroller. The box is built accordingly so that the SO_2 and CO gas will fill the space to be observed and the fan applied to circulate the contained air. Figure 2 shows the sketch of the air quality monitoring box.

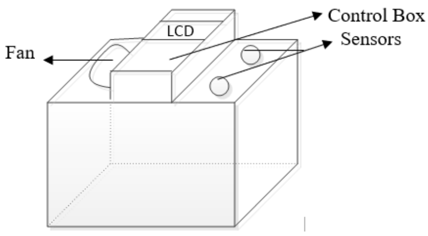


Figure 2. Overall mechanical design

2.2. MQ-136 And TGS2201 circuit

MQ-136 can measure SO_2 concentration from 1 ppm to 200 ppm. The sensor has an output analog of 0 V to 5 V, the higher the concentration, the higher the voltage output. The sensor can stably measure when heated for up to 20 seconds since the sensor has an internal conductor. Figure 3 displays the MQ-136 sensor module.

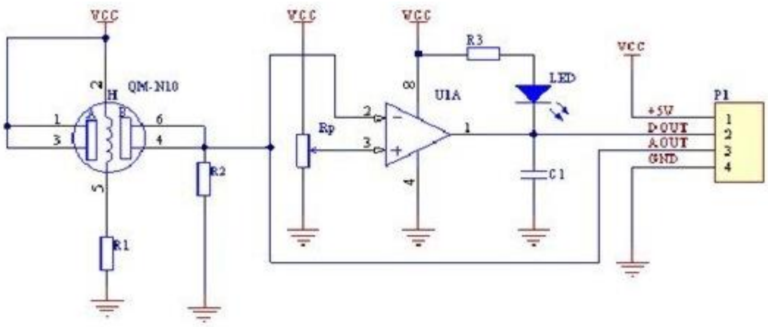


Figure 3. MQ-136 sensor module

TGS2201 was applied to measure CO and SO_2 concentrate. The sensor can measure from 0 ppm up to 1000 ppm. The sensor has an output analog of 0 V to 5 V, the higher the concentration, the higher the voltage output. Figure 4 shows the TGS 2201 sensor module.

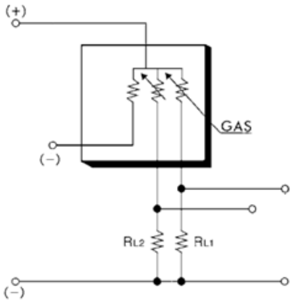


Figure 4. TGS 2201 sensor module

2.3. Software design

The fuzzy logic algorithm consists of three steps, which is fuzzification, fuzzy inference, and defuzzification. Fuzzification contains an equation of the membership function that is applied to convert crisp value to fuzzy value. The process is done into CO ppm error, SO_2 ppm error, and fan driver pulse width modulation (PWM). Fuzzy inference contains rule bases and implication methods acquired using the Mamdani method to decide the desired control. The output of fuzzy inference is the value of fan driver PWM which is still in the form of fuzzy membership degree value. Defuzzification is applied to convert PWM in fuzzy into the crisp value. The process is done using Takagi Sugeno method. Figure 5 shows the flowchart of the fuzzy logic process.

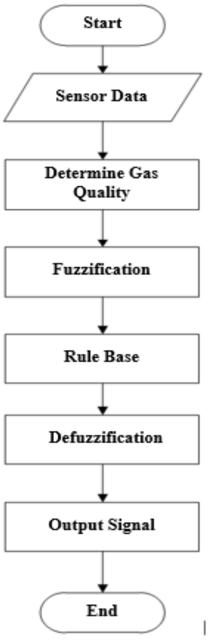


Figure 5. Fuzzy algorithm flowchart

2.3.1. CO fuzzification

CO fuzzification is applied to determine the CO ppm levels for the fuzzification. There are 5 categories to differentiate the CO ppm levels which will be applied to the system's fuzzy, which is good, medium, bad, very bad, and dangerous. The rule base of each category is shown below with each category containing at least three rules. Figure 6 shows the input membership function of CO ppm error.

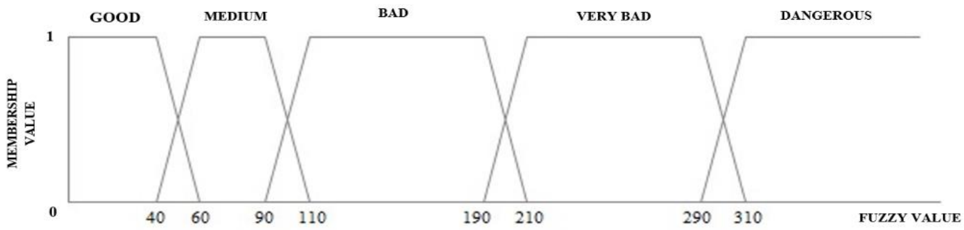


Figure 6. Input membership function of CO ppm error

$$Good\ CO: \mu_{CO}(x) = \begin{cases} 1;\ x < 40 \\ \frac{-x+60}{20};\ 40 \le x \le 60 \\ 0; x > 60 \end{cases}$$

$$Medium\ CO: \mu_{CO}(x) = \begin{cases} 0; x<40 \\ \frac{x-40}{20}; 40 \le x \le 60 \\ 1; 60<x<90 \\ \frac{110-x}{20}; 90 \le x \le 110 \\ 0; x>110 \end{cases}$$

$$Bad\ CO: \mu_{CO}(x) = \begin{cases} 0; x<90 \\ \frac{x-90}{20}; 90 \le x \le 110 \\ 1; 110<x<190 \\ \frac{210-x}{20}; 190 \le x \le 210 \\ 0; x>210 \end{cases}$$

$$Very\ Bad\ CO: \mu_{CO}(x) = \begin{cases} 0; x<190 \\ \frac{x-190}{20}; 190 \le x \le 210 \\ 1; 210<x<290 \\ \frac{310-x}{20}; 290 \le x \le 310 \\ 0; x>310 \end{cases}$$

$$Dangerous\ CO: \mu_{CO}(x) = \begin{cases} 0; x<290 \\ \frac{x-290}{20}; 290 \le x \le 310 \\ 1;\ 310 < x \end{cases}$$

2.3.2. SO_2 fuzzification

SO_2 fuzzification is applied to determine the SO_2 ppm levels for the fuzzification. There are 3 categories to differentiate the SO_2 ppm levels which will be applied to the system's fuzzy, which are good, medium, and bad. The rule base of each category is shown below with each category containing at least three rules. Figure 7 shows the input membership function of SO_2 ppm error.

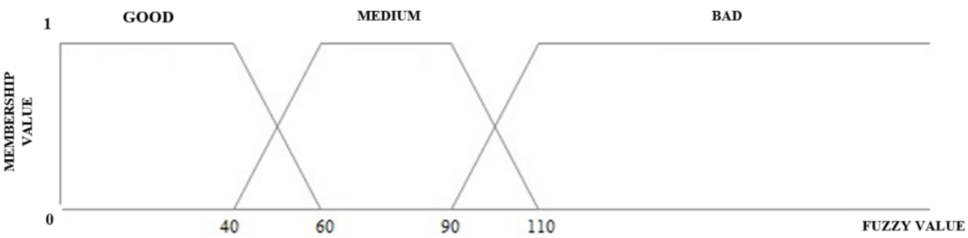


Figure 7. Input membership function of SO_2 ppm error

$$Good\ SO2: \mu_{SO2}(x) = \begin{cases} 1;\ x < 40 \\ \frac{-x+60}{20};\ 40 \le x \le 60 \\ 0; x > 60 \end{cases}$$

$$Medium\ SO2: \mu_{SO2}(x) = \begin{cases} 0; x<40 \\ \frac{x-40}{20}; 40\leq x\leq 60 \\ 1; 60<x<90 \\ \frac{110-x}{20}; 90\leq x\leq 110 \\ 0; x>110 \end{cases}$$

$$Bad\ SO2: \mu_{SO2}(x) = \begin{cases} 0; x<90 \\ \frac{x-90}{20}; 90\leq x\leq 110 \\ 1;\ 110 < x \end{cases}$$

2.3.3. Fuzzy inference system

The information on the fuzzification for each gas type is then applied to determine the fuzzy inference system membership function. The system is applied to enable the blower to activate based on the condition. There are 4 categories to differentiate blower activation, which are medium, bad, very bad, and dangerous. Figure 8 shows the membership function for the fuzzy inference system, along with the rule base of each category is shown in the following Table 1.

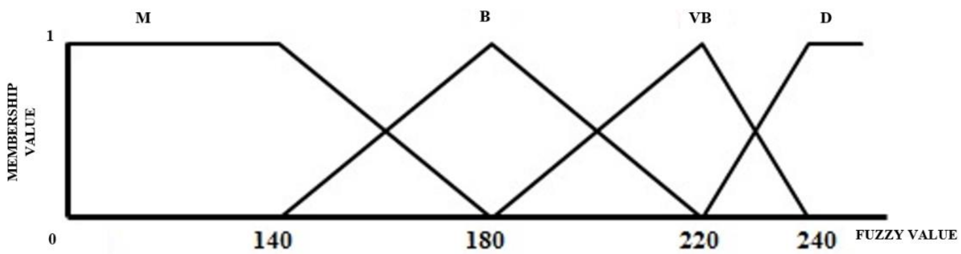


Figure 8. Output membership function for blower

Table 1. Blower rule base

SO_2\CO	Good	Medium	Bad	Very bad	Dangerous
Good	“OFF”	M	B	VB	D
Medium	M	M	VB	D	D
Bad	B	VB	VB	D	D

3. RESULTS AND DISCUSSION

3.1. MQ-136 and TGS2201 testing

The test is done by detecting the converted analog-to-digital (ADC) input value. To acquire the compatible ppm value, an exponential function is required from the sensor characteristic graph from each datasheet. Figures 9 and 10 show both the plot diagram of TGS2201 and MQ-136, with each graph describing the tread line plot between gas quality (ppm) and the input voltage. The X-axis shows the sensor input voltage while The Y-axis shows the gas quality ppm rate.

The test and calibration are applied to the TGS2201 sensor to observe the performance of the sensor based on the tread line plot of Figure 9. The test is applied by measuring the CO ppm value based on the Voltage Input value, which then determined the gas quality from each data set. the quality of gas-determined CO with ppm between 0 to 50 is considered to be good, and 51 to 100 is considered medium. Otherwise, it is considered to be a bad condition. The test is done five times with each of the data showing the different voltage input and CO ppm values which will show the gas quality based on the condition above. From the 5^{th} test, the CO value is 112 ppm which the gas quality is considered to be bad. Table 2 shows the TGS2201 test results.

The test and calibration are also applied to the MQ-136 sensor to observe the performance of the sensor based on the tread line plot of Figure 10. The test is applied by measuring SO_2 ppm value based on voltage input value, which then determined the gas quality from each data set. The quality of gas determined SO_2 with ppm between 0 to 50 is considered to be in good condition. The test is done five times with each of the data showing the different voltage input and SO_2 ppm values which will show the gas quality based on the condition above. From the test result, it is shown that gas ppm cannot get higher since the motor exhaust gas has not contained more SO_2 than CO gas. Table 3 shows the MQ-136 test results.

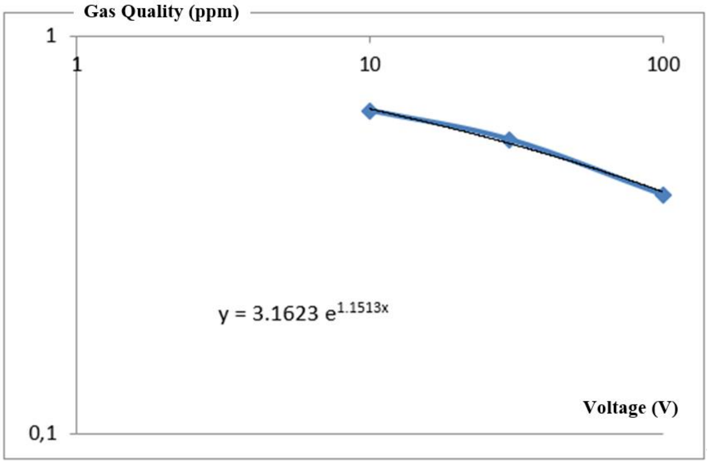


Figure 9. TGS2201 sensor tread line plot of

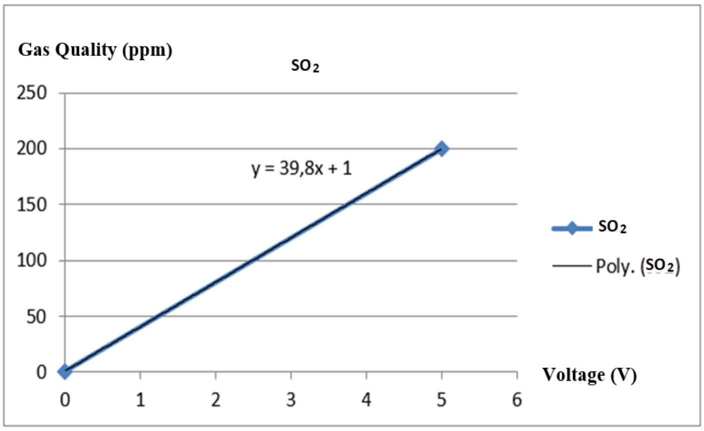


Figure 10. MQ-136 sensor tread line plot

Table 2. TGS2201 test results

Voltage input (V)	CO ppm value	Gas quality
1,04	10	Good
1,55	18	Good
2,53	58	Medium
2,85	84	Medium
3,1	112	Bad

Table 3. MQ-136 test results

Voltage input (V)	SO_2 ppm value	Gas quality
0,2	9	Good
0,3	13	Good
0,33	14	Good
0,42	18	Good
0,45	19	Good

3.2. Overall system test

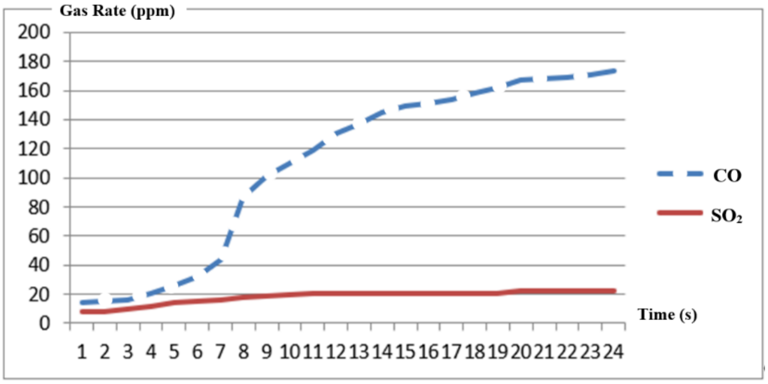
To test the integrated system, exhaust smoke in a 1,500 ml plastic container is transferred into the box with no fan. the data is also compared when the cigarette smoke in a 1,500 ml plastic container is transferred into the box. Table 4 shows the gas data between exhaust and cigarette smoke, while the following Figure 11 shows the data graph, with each graph describing the test result for exhaust smoke and cigarette smoke.

Table 4. System test result on exhaust and cigarette smoke

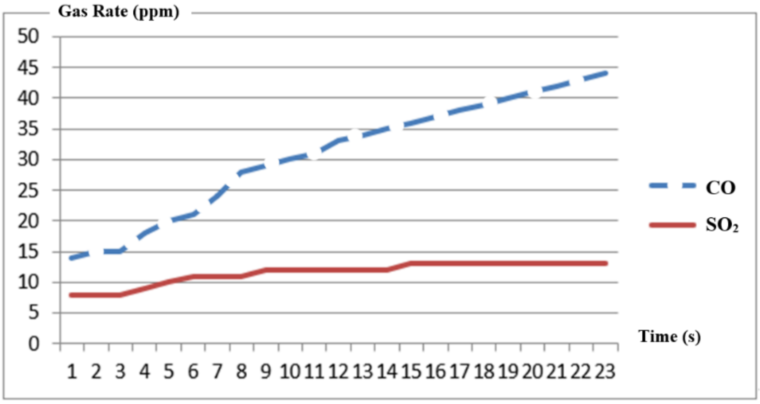
Exhaust smoke			Cigarette smoke		
CO	SO_2	Gas quality	CO	SO_2	Gas quality
16	10	Good	14	8	Good
21	12	Good	15	8	Good
26	14	Good	15	8	Good
32	15	Good	18	9	Good
44	16	Good	20	10	Good
87	18	Medium	21	11	Good
101	19	Bad	24	11	Good
110	20	Bad	28	11	Good
119	21	Bad	29	12	Good
131	21	Bad	30	12	Good
137	21	Bad	31	12	Good
145	21	Bad	33	12	Good
149	21	Bad	35	12	Good
151	21	Bad	36	13	Good

Figure 11 contains side-to-side comparison between two images of graphics, with Figure 11(a) is test result graph with data on exhaust smoke and Figure 11(b) is on cigarette smoke. From Table 4 and the comparison in Figures 11(a) and 11(b), it is concluded that the cigarette quality gas in the box is not much higher than exhaust gas. the quality of exhaust smoke in 1,500 ml container reaches less than 200 ppm, which is considered to be bad quality. While the quality of cigarette smoke in 1,500 ml container reach less than 50 ppm, which is considered to be much better or good quality.

To add the validation of the system function, the test is added by outdoor testing. The test result data will be compared to the data from the previous test, then the graph will be generated and compared with exhaust gas and cigarette gas. Table 5 is the test result data and Figure 12 is the data graph of outdoor air.



(a)



(b)

Figure 11. Test result graphs with data on (a) exhaust smoke and (b) cigarette smoke

Table 5. System test result with outdoor air

Exhaust smoke			Cigarette smoke			Outdoor air		
CO	SO_2	Gas quality	CO	SO_2	Gas quality	CO	SO_2	Gas quality
16	10	Good	14	8	Good	23	12	Good
21	12	Good	15	8	Good	23	12	Good
26	14	Good	15	8	Good	24	12	Good
32	15	Good	18	9	Good	27	12	Good
44	16	Good	20	10	Good	31	14	Good
87	18	Medium	21	11	Good	34	13	Good
101	19	Bad	24	11	Good	38	14	Good
110	20	Bad	28	11	Good	41	14	Medium
119	21	Bad	29	12	Good	44	14	Medium
131	21	Bad	30	12	Good	51	15	Medium
137	21	Bad	31	12	Good	51	15	Medium
145	21	Bad	33	12	Good	50	14	Medium
149	21	Bad	35	12	Good	49	14	Medium
151	21	Bad	36	13	Good	47	14	Medium

From the test result described in Table 5 and Figure 12, it is concluded that the system is working properly according to the initial system design and purpose. With the outdoor air quality, the more vehicle passes through, the worsening the air quality. While the less vehicle passes through, the better the air quality. This situation is also supported by the nature factor such as blowing wind and shading of trees. Figure 13 shows the graph comparison between indoor air quality and outdoor air quality.

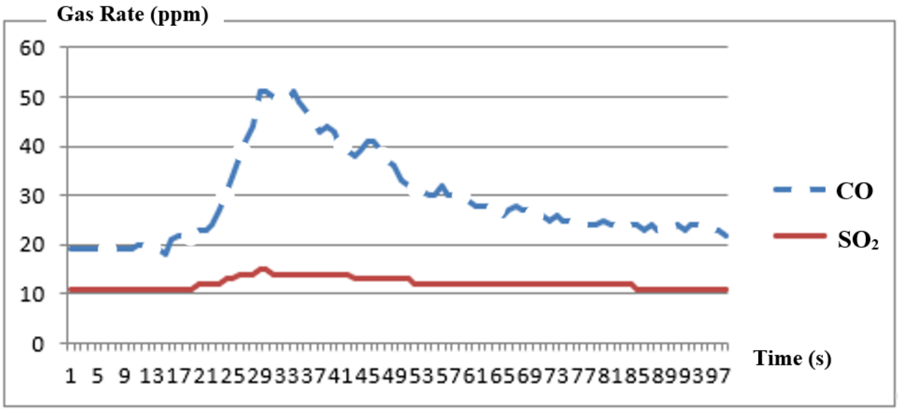


Figure 12. Test result graphics of outdoor air quality

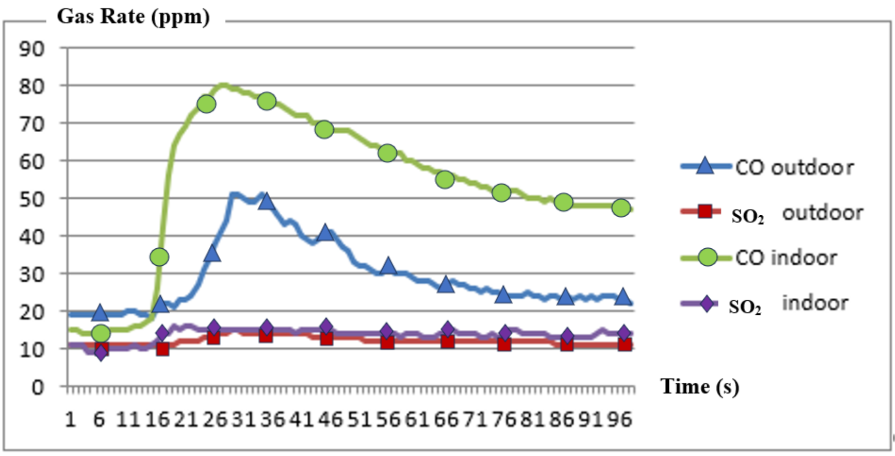


Figure 13. Comparison graph of indoor air quality and outdoor air quality

4. CONCLUSION

In this research, the prototype of air quality monitoring is proposed. From the result of the research, it is concluded that the designed system is working with some tests of the system proving to be working according to the initial purpose of the design. CO gas sensor towards the transportation exhaust gas is much higher compared to the SO_2 gas. The blower will be turned on when the gas quality in the box is reaching a ppm value above 50. When it is tested outdoors, the quality of the air is affected by the environment such as wind and the shading of trees. The comparison of sensor readings indoors and outdoors is that the gas quality of 29 ppm. The cigarette quality gas in the box is not much higher than exhaust gas. the quality of exhaust smoke in 1,500 ml container reaches less than 200 ppm, which is considered to be bad quality. While the quality of cigarette smoke in 1,500 ml container reach less than 50 ppm, which is considered to be much better or good quality.

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