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Design Analysis of a Portable Air Quality Detection Device for Passenger Cabin Vehicles

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***Abstract*—Passenger vehicles, such as private and public cars, can spend long periods of time indoors, especially during traffic jams or long journeys. Closed cabins with limited air circulation can potentially reduce air quality due to exposure to carbon monoxide (CO) from exhaust leaks and R-134a refrigerant from air conditioning systems. Both gases are colorless and odorless, making them difficult for humans to detect directly. Furthermore, Indonesia's high temperature and humidity can impact cabin comfort. This research aims to design an air quality detection system in a car cabin based on Arduino Uno R3 to detect CO, R-134a, temperature, and humidity gases and provide early warnings when air conditions exceed safe limits. The research method used is Research and Development (R&D) by utilizing MQ-7, MQ-139, and DHT22 sensors integrated with Arduino Uno R3. The results of sensor readings are displayed via a 20x4 LCD with a buzzer and LED as early warning indicators. The research stages include literature review, system requirements determination, hardware and software design, assembly, and functional system testing. Based on the system testing results, the Arduino Uno R3-based air quality detection device for car applications can work well according to its designed function and is able to provide early warnings when air quality exceeds a predetermined threshold.**

***Keywords*—DHT22, carbon monoxide, air quality, MQ-7, MQ-139, R-134a**

I. Introduction

The use of passenger cars in Indonesia continues to increase in line with the high demand for public mobility. Data from the Central Statistics Agency (BPS) shows that the number of passenger cars in Indonesia continues to increase annually until it reaches 20,907,972 units in 2025. This data shows that the use of cars is quite popular for mobility needs. If the use of cars is used for daily needs, many users spend quite a long time in the vehicle cabin, especially during traffic jams, long trips, or holiday seasons. The car cabin, which is a closed space with limited air circulation, has the potential to experience a decrease in air quality due to the accumulation of various pollutants originating from outside and from inside the vehicle [1].

Carbon monoxide (CO) is one of the main pollutants from vehicle emissions and the most common cause of gas poisoning in humans. This gas can enter the cabin through leaks in the exhaust system or gaps in the vehicle body. Because it is colorless, odorless, and undetectable by the human senses, carbon monoxide exposure often goes unnoticed until it causes health problems, ranging from headaches, shortness of breath, decreased consciousness, and death due to hypoxia [2].

In addition to carbon monoxide, refrigerant leaks (R-134a) from a vehicle's air conditioning (AC) system also have the potential to reduce air quality in the cabin. Refrigerant gases such as R-134a have similar characteristics to carbon monoxide, namely odorless, colorless, and not directly detected by the human senses [3]. Leaks in the evaporator can cause refrigerant gas to be released directly into the cabin without the user being aware, especially since the AC system can still operate even though the amount of refrigerant is starting to decrease. Exposure to R-134a in high concentrations can cause irritation, respiratory problems, nervous system disorders, and even death. Several cases of poisoning due to refrigerant leaks in vehicles in Indonesia show that this risk requires more attention.

Besides the presence of harmful gases, temperature and humidity also affect comfort and air quality in the cabin. High temperatures can increase the release of Volatile Organic Compounds (VOCs) from vehicle interior materials, while less than ideal humidity can reduce passenger comfort and support the growth of microorganisms [4]. Therefore, monitoring temperature and humidity is necessary as supporting parameters in evaluating cabin air quality.

II. Research Method

This research uses the Research and Development (R&D) method to design and build an applicable air quality detection system in the car cabin with early warning as a passive mitigation measure. The R&D method is an approach used to develop or produce a product and test its performance [5], [6]. The system developed integrates an MQ-7 sensor to detect carbon monoxide (CO) gas, an MQ-139 sensor to detect refrigerant gas (R-134a), and a DHT22 sensor to measure air temperature and humidity. The research stages include those shown in Figure 1.

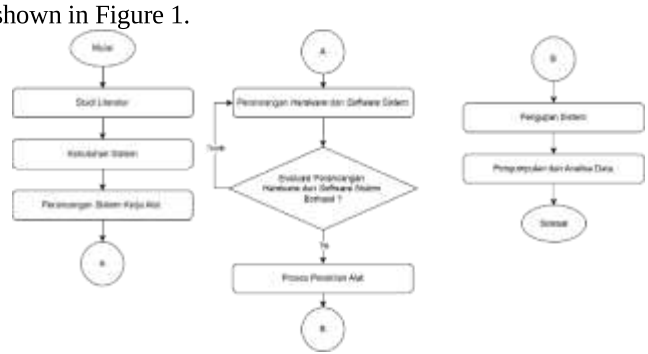

Fig. 1. Research Flowchart

III. RESULTS AND DISCUSSION

A. Tool Mechanism

The working mechanism of the tool is arranged based on a system flow diagram with a working sequence of the tool starting from heating the sensor for 60 seconds, initialization, reading sensor data, data processing by Arduino Uno R3, determining air quality conditions based on threshold values based on Table 1, to delivering information via LCD and activating early warnings via LCD, LED and buzzer with output based on air quality conditions shown in Figures 2 and 3.

TABLE I. THRESHOLD FOR DETERMINING SYSTEM CONDITIONS

Condition	Carbon Monoxide Concentration (ppm)	R-134a concentration (ppm)
Normal	CO <50 ppm	R-134a <900 ppm
Alert	50 ppm ≤CO <150 ppm	900 ppm ≤R-134a <1000 ppm
Alert	50 ppm ≤CO <150 ppm	R-134a <900 ppm
Alert	CO <50 ppm	900 ppm ≤R-134a <1000 ppm
Danger	CO ≥150 ppm	R-134a ≥1000 ppm
Danger	CO ≥150 ppm	900 ppm ≤R-134a <1000 ppm
Danger	CO ≥150 ppm	R-134a <900 ppm
Danger	50 ppm ≤CO <150 ppm	R-134a ≥1000 ppm
Danger	CO <50 ppm	R-134a ≥1000 ppm

Fig. 2. Flowchart of Tool System Part 1

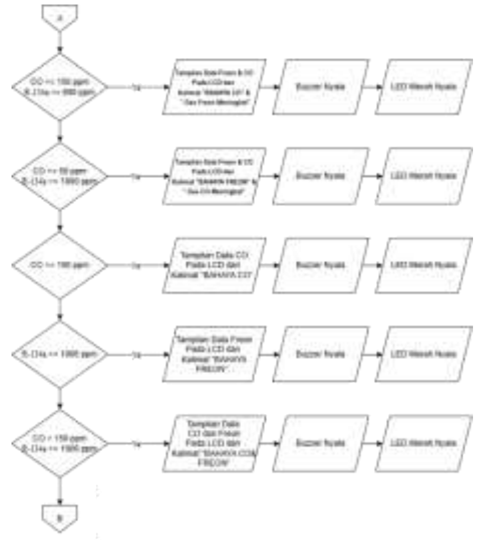

Fig. 3. Flowchart of Tool System Part 2

Figure 2 and Figure 3 show the flow diagram of the air quality detection system that explains the working sequence of the tool. Arduino Uno R3 reads data from the MQ-7, MQ-139, and DHT22 sensors. From the gas sensor, analog data results are obtained which are converted into digital values via ADC, then the ADC value is processed into gas concentration (ppm) using a non-linear regression equation that has been substituted based on the characteristic curve of each gas sensor as in Equation (1) [7].

$$ppm = \left[\frac{R_S}{R_0 \times a}\right]^{\frac{1}{b}} \tag{1}$$

The R0 value can be determined from the clean air curve in the gas sensor sensitivity characteristic graph, while the a and b values are determined from the gas curve to be detected in the characteristic graph. The Rs value is the sensor resistance at various gas concentrations with units of kΩ. Next, the Arduino will compare the measurement results with the threshold value to determine the air quality condition.

Monitoring results are displayed in real time on an LCD display containing carbon monoxide, R-134a, temperature, and humidity concentrations. If gas concentrations exceed a predetermined threshold, the system automatically activates an LED and buzzer as an early warning. The entire process of sensor reading, data processing, and warning is repeated throughout the system's operation so that the air quality inside the cabin can be continuously monitored.

B. Hardware Design Results

1) Wiring Design Results

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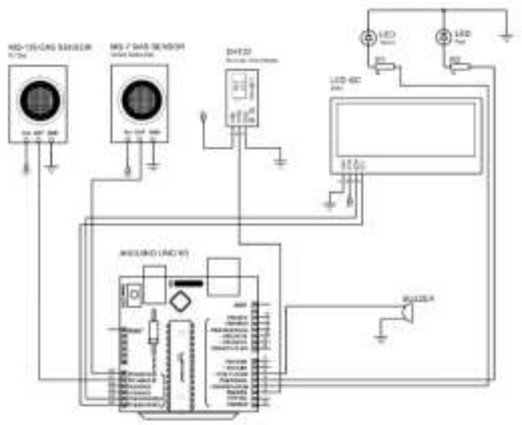

Fig. 4. Air Quality Detection System Wiring Circuit

Figure 4 shows a wiring diagram depicting the relationships between components with the Arduino Uno R3 as the system's central controller. This diagram serves as an assembly reference to ensure all voltage source, input, and output lines are connected as designed so the system can operate properly.

Fig. 5. Results of Installing Cables from Each Component to the Arduino Board

Figure 5 shows the wiring design realized from the wiring diagram of the device's system. The assembly process was carried out according to the wiring diagram and pin configuration so that all components function according to the system design. After assembly was complete, the circuit was tested to ensure each component received the appropriate voltage supply and that all system connections and functions worked as designed.

2) Tool Casing Design Results

The casing is designed to protect and house the system components. The casing's dimensions are adjusted to the size of the holder. The phone is mounted on the car dashboard, resulting in a portable design. The casing is made using 3D printing with PLA+ (Polylactic Acid Plus) material. The casing design concept is shown in Figure 6.

Fig. 6. Casing Concept

Figure 7 shows the results of the casing design realized through 3D printing.

Fig. 7. Tool Assembly Results

The casing is made using PLA+ (Polylactic Acid Plus) material because it has better mechanical strength and print quality than standard PLA, so it can produce precise dimensions for placing electronic components. The casing has dimensions of 11.6 × 10.1 × 5.5 cm whose layout is adjusted to the dimensions of the components and holder for a cell phone on a car dashboard. While PLA+ is sufficient for prototyping, the use of materials with higher thermal resistance may be considered in future development to make it more suitable for long-term use in the cabin.

Furthermore, the casing is equipped with ventilation in each sensor area to ensure ambient air can directly reach the sensor surface. The position of the sensors is also arranged with distance and layout that consider the influence of each sensor on the detected value, such as the effect of heat from the MQ sensor heater on the DHT22 sensor, which can affect the accuracy of temperature readings.

C. Software Design Results

1) Initialize R0 Sensor Value

Before being used to detect gas concentration, the MQ-7 and MQ-139 sensors are initialized to obtain a reference resistance value (R0) in clean air conditions. The R0 value is used as a reference in calculating the RS/R0 ratio [8].

$$Rasio\ Udara\ Bersih = \frac{R_S}{R_0} \tag{2}$$

RS: Sensor resistance in various gas concentration values (kΩ).
R0: Sensor resistance in clean air (kΩ).

The RS/R0 ratio is used as the basis for calculating gas concentration (ppm) based on the sensitivity characteristics of each sensor. The R0 value is calculated using the clean air ratio parameter obtained from the sensitivity curves of the MQ-7 and MQ-139 sensors in clean air conditions. In the initialization stage, each sensor takes 30 readings, then the values are averaged to obtain the R0 value which is used as a reference in calculating gas concentrations during system operation.

a) MQ-7 Sensor

The following data shows 5 coordinate points on the MQ-7 characteristic curve which shows the relationship between the sensor resistance ratio (RS/R0) and the concentration in ppm units in clean air.

TABLE II. COORDINATE POINT DATA OF MQ-7 SENSOR CHARACTERISTIC CURVE FOR CLEAN AIR

No	ppm	R_S/R_0
1	50	25.75
2	100	25.75
3	400	25.75
4	1000	25.75
5	4000	25.75
Average R_0		25.75

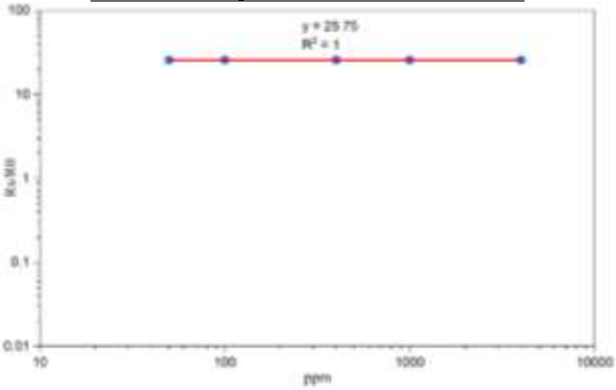

Fig. 8. Graph of MQ-7 Power Sensor Regression Results for Clean Air

From this data, the clean air ratio value of the MQ-7 sensor is obtained, namely:

$$\frac{R_S}{R_0} = 25{,}75 \tag{3}$$

After the clean air ratio value is obtained, the Arduino will read the sensor analog data to calculate the sensor resistance value (Rs) using the R0 value. The implementation of the R0 value calculation in the program is shown in Figure 9.

Fig. 9. Program for Calculating the Value of R0 for Arduino (MQ-7)

b) MQ-139 Sensor

The following data shows 6 coordinate points on the MQ-139 characteristic curve which shows the relationship between the sensor resistance ratio (RS/R0) and the concentration in ppm units in clean air.

TABLE III. COORDINATE POINT DATA OF THE MQ-139 SENSOR CHARACTERISTIC CURVE FOR CLEAN AIR

No	ppm	R_S/R_O
1	10	3.55
2	30	3.55
3	50	3.55
4	70	3.55
5	200	3.55
Average R_0		3.55

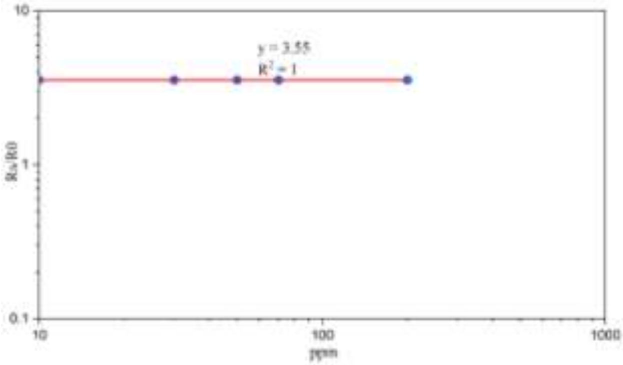

Fig. 10. Graph of MQ-139 Power Sensor Regression Results for Clean Air

From this data, the clean air ratio value of the MQ-139 sensor was obtained, namely:

$$\frac{R_S}{R_0} = 3{,}55 \tag{4}$$

After the clean air ratio value is obtained, the Arduino will read the sensor analog data to calculate the sensor resistance value (Rs) using the R0 value. The implementation of the R0 value calculation in the program is shown in Figure 11.

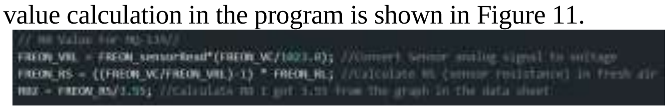

Fig. 11. R0 Value Calculation Program for Arduino (MQ-139)

2) Analog Sensor Data Conversion

The MQ-7 and MQ-139 sensors produce analog data output that is read by the Arduino Uno R3 as an ADC value. This value is then converted to gas concentration (ppm) using a mathematical algorithm that refers to the sensitivity characteristic curve in the sensor datasheet. The points on the curve are digitized and a curve fitting process is carried out using the Origin application to obtain a mathematical equation that represents the trendline of the gas to be detected on each sensor.

a) MQ-7 Sensor

The MQ-7 sensor conversion algorithm was designed based on the carbon monoxide (CO) sensitivity characteristic curve in the sensor datasheet. Ten coordinate points showing the relationship between the sensor resistance ratio (RS/R0) and the carbon monoxide concentration (ppm) were used as the basis for the conversion equation.

TABLE IV. COORDINATE POINT DATA OF MQ-7 SENSOR CHARACTERISTIC CURVE FOR CARBON MONOXIDE

No	ppm	R_S/R_O
1	50	1.58443
2	70	1.24854
3	90	1.06441
4	100	1

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5	200	0.60562
6	400	0.37853
7	600	0.29184
8	800	0.24556
9	1000	0.21585
10	4000	0.09024

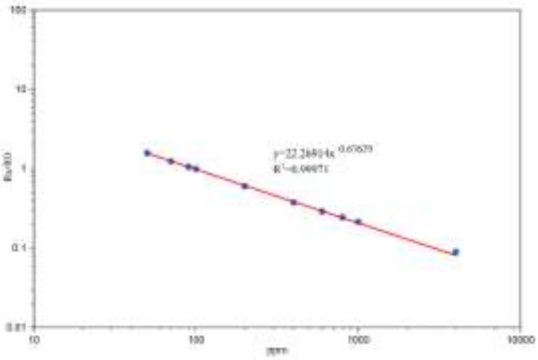

Fig. 12. Graph of MQ-7 Sensor Power Regression Results for Carbon Monoxide

Based on the results of non-linear regression, the MQ-7 sensor trendline equation is obtained as follows:

$$y = 22.26914x^{-0.67629} \tag{5}$$

The constant value is then substituted into Equation (1) to obtain the conversion equation for carbon monoxide gas concentration in ppm units.

$$ppm = \left[\frac{Ratio}{22.26914}\right]^{\frac{1}{-0.67629}} \tag{6}$$

This equation is then implemented in the Arduino program using the pow() function so that the gas concentration calculation can be done automatically.

```
VRL1 = (gasADC1)*(VC1/1023.0); //Convert Sensor analog signal to voltage
RS1 = ((VC1/VRL1)-1)*RL1; //Calculate RS in fresh air
ratio1 = RS1/R01; // Get resistance ratio
gasPPM1 = pow((22.26914/ratio1),(1/0.67629));
```

Fig. 13. ppm Value Calculation Program for Arduino (MQ-7)

b) MQ-139 Sensor

The MQ-139 sensor conversion algorithm was designed using the same procedure as the MQ-7 sensor. The sensitivity characteristic curve to R-134a refrigerant gas in the datasheet was used to obtain the relationship between the sensor resistance ratio (RS/R0) and gas concentration. A total of 10 coordinate points on the curve were used as the basis for forming the conversion equation.

TABLE V. Coordinate Point Data of the MQ-139 Sensor Characteristic Curve for Refrigerant

No	ppm	Hospital/Regional Hospital
1	10	2.80812
2	20	2.33701
3	30	2.11342
4	40	1.95774
5	50	1.82946
6	60	1.74928
7	70	1.67627
8	80	1.62752
9	100	1.54433
10	200	1.33537

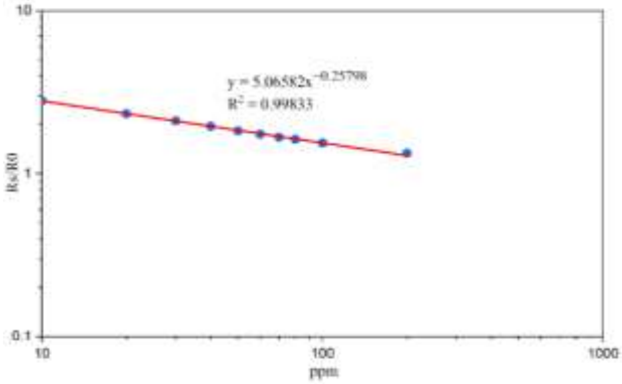

Fig. 14. Graph of MQ-139 Power Sensor Regression Results for Refrigerant

Based on the results of non-linear regression, the trendline equation for the MQ-139 sensor is obtained as follows:

$$y = 5.06582x^{-0.25798} \tag{7}$$

The constant value is then substituted into Equation (1) to obtain the conversion equation for the R-134a gas concentration in ppm units.

$$ppm = \left[\frac{Ratio}{5{,}06582}\right]^{\frac{1}{-0{,}25798}} \tag{8}$$

This equation is then implemented in the Arduino program using the pow() function to calculate the gas concentration automatically.

```
VRL2 = (gasADC2)*(VC2/1023.0); //Convert Sensor analog signal to voltage
RS2 = ((VC2/VRL2)-1)*RL2; //Calculate RS in fresh air
ratio2 = RS2/R02; // Get resistance ratio
gasPPM2 = pow((5.06582/ratio2),(1/0.25798));
```

Fig. 15. Program for Calculating ppm Values for Arduino (MQ-139)

D. Functionality Test Results

1) Voltage Source Test Results

Voltage source testing is carried out to ensure that the voltage source used is capable of supplying power to all components according to operational requirements.

TABLE VI. Voltage Source Test Results

No	Test Point	Working Voltage (V)	Rated Voltage (V)	Results
1	Arduino Uno R3 Pin 5V	±5.0	4.72	In accordance
2	MQ-7 Sensor	5.0 ± 0.2	4.87	In accordance
3	MQ-139 Sensor	5.0 ± 1	4.25	In accordance
4	DHT22 Sensor	3,3-6	4.52	In accordance
5	20×4 I2C LCD	4.5-5.5	4.50	In accordance
6	Yellow LED	2.0 – 2.2	2.08	In accordance
7	Red LED	1.8 – 2.2	1.95	In accordance
8	Buzzer	±2.0	2.08	In accordance

Based on the test results in Table 6, the voltage received by each component is in the range of 1.95 - 4.87 V. Although there is a slight difference between the nominal voltage and the

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measured results due to path resistance and circuit loading, all components still function properly. These results indicate that the voltage source and wiring on the device are successful and able to distribute the voltage as needed so as not to affect component performance.

2) Output Test Results

Output testing was conducted to verify that the output device provides information and warnings according to the air quality conditions programmed into the Arduino with the output reference as shown in Figures 2 and 3. The testing was conducted in a 30 × 30 cm acrylic test chamber with exposure to carbon monoxide gas originating from motorcycle emissions and pure R-134a refrigerant gas. During the testing, the response of the LCD, yellow LED, red LED, and buzzer was observed to evaluate their suitability to the designed conditions. The results of the output testing are presented in Table 7.

TABLE VII. OUTPUT TEST RESULTS

No	Possible Conditions: CO levels (ppm)	Possible Conditions: R-134a content (ppm)	Criteria: *Output*	Criteria: Performance	The results obtained
1	< 50	< 900	LCD	All sensor data	In accordance
			Buzzer	OFF	
			LED	OFF	
2	50 - 149	< 900	LCD	CO Data	In accordance
				Sentence "CO Gas Increases"	
			Buzzer	ON	
			LED	Yellow ON	
3	< 50	900 - 999	LCD	R-134a Data	In accordance
				Sentence "Freon Gas Increases"	
			Buzzer	ON	
			LED	Yellow ON	
4	50 - 149	900 - 999	LCD	CO Data	In accordance
				R-134a Data	
				Sentence "CO & Freon Increase"	
			Buzzer	ON	
			LED	Yellow ON	
5	≥150	900 - 999	LCD	CO Data	In accordance
				R-134a Data	
				The sentence "DANGER OF CO GAS" and Sentences "Freon Gas Increases"	
			Buzzer	ON	
			LED	Red ON	
6	50 - 149	≥1000	LCD	R-134a Data	In accordance
				CO Data	
				The sentence "DANGER OF FREON GAS" and Sentences "CO Gas Increases"	
			Buzzer	ON	
			LED	Red ON	
7	≥150	< 900	LCD	CO Data	In accordance
				The sentence "DANGER OF CO GAS"	
			Buzzer	ON	
			LED	Red ON	
8	0 - 49	≥1000	LCD	R-134a Data	In accordance
				The sentence "DANGER OF FREON GAS"	
			Buzzer	ON	
			LED	Red ON	
9	≥150	≥1000	LCD	CO Data	In accordance
				R-134a data	
				The sentence "DANGER OF CO & FREON"	
			Buzzer	ON	
			LED	Red ON	

Based on the test results, the MQ-7, MQ-139, and DHT22 sensors are capable of reading air quality parameters simultaneously. The data obtained is successfully processed by the Arduino Uno R3 and displayed on the LCD in the form of gas concentration in ppm units, temperature in Celsius units, humidity in percent units (%), and air quality status in each condition. Other outputs for the warning system such as LEDs and buzzers also function according to each predetermined condition. Overall, the test results show that the system works well in an integrated manner and is capable of carrying out monitoring and early warning functions in accordance with the research objectives.

IV. CONCLUSION

Based on the results of the design, realization, and testing of the Arduino Uno R3-based air quality detection system for applications in car cabins, the following conclusions were obtained.

1) Successfully designed and realized an Arduino Uno R3-based air quality detection system that is capable of detecting carbon monoxide (CO) gas, refrigerant gas (R-134a), as well as temperature and humidity using MQ-7, MQ-139, and DHT22 sensors.

2) The system is capable of reading and processing sensor data in real-time, displaying measurement results on the LCD, and providing early warnings via LEDs and buzzers based on predetermined threshold values.

3) The test results show that all system components function as designed and work in an integrated manner, so that they are able to carry out air quality monitoring and early warning functions well.

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