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Research on Design and Manufacture of System to Measure and Warning Air Quality, Temperature, and Air Humidity in Cars

Tuan Phan Van, Bang Nguyen Khac
Faculty of Engineering and Technology, Tra Vinh University, Vietnam

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ABTRACT
Air quality inside vehicles has a direct impact on the health and comfort of passengers, particularly in heavily polluted urban traffic environments. This study presents the design and development of an integrated monitoring and alert system for air quality, temperature, and humidity within automobiles. The system is built upon a combination of environmental sensors and an Arduino-based microcontroller unit. It is capable of detecting when measured parameters exceed predefined safety thresholds and provides real-time alerts to the occupants. Additionally, the system proposes automatic control solutions for the vehicle's ventilation and humidity regulation systems in cases of excessively high or low humidity, thereby improving the overall in-cabin environment. Experimental evaluations demonstrate that the system operates reliably, with fast response times and consistent performance across a range of air quality conditions. The proposed solution enhances driver and passenger experience by ensuring a safer and more comfortable in-vehicle environment.
Keywords: *In-vehicle environmental monitoring system; Humidity, CO, CO_2, dust; Arduino microcontroller*.

I. INTRODUCTION

In recent years, air quality inside vehicle cabins has emerged as a critical research topic, not only affecting passenger comfort but also having direct implications on driver health and concentration. According to a report by the World Health Organization (WHO) [1], more than 90% of the global population is exposed to polluted air, leading to approximately 3.8 million deaths annually due to related illnesses. Particularly, fine particulate matter (PM2.5), which can penetrate deep into the respiratory system, is a major cause of serious diseases such as stroke, cardiovascular disorders, and cancer.

In addition, toxic gases such as carbon monoxide (CO) a byproduct of incomplete fuel combustion pose significant risks when accumulated in enclosed spaces like vehicle cabins. CO exposure can impair cognitive function and increase the likelihood of traffic accidents. Although not always at lethal levels, high CO concentrations in vehicle cabins can lead to hypoxia, fatigue, and deterioration of respiratory and cardiovascular health. Notably, the issue of children being left unattended in vehicles continues to occur, and real-time CO monitoring can help mitigate this risk.

The microclimatic factors inside vehicles, including temperature and humidity, also play a crucial role. High humidity fosters the growth of bacteria and mold, increasing the risk of respiratory infections and interior material degradation. Conversely, low humidity may cause dry skin, irritation of the mucous membranes, and other health-related issues for occupants.

Globally, numerous studies have been conducted to assess and improve in-cabin air quality. Research by Zhongchao Tan et al. [2] at the University of Waterloo, Canada, demonstrated that concentrations of CO, CO_2, and NO_2 inside trucks were significantly higher than in office environments. Similarly, a team from the Global Centre for Clean Air Research (GCARE) at the University of Surrey, UK [3], found that although vehicle ventilation systems can reduce pollutant levels, they may also introduce outdoor pollutants into the cabin. In Vietnam, several studies on air quality monitoring systems have also been carried out. The team led by Nguyen Van Thien et al. [4] developed a multi-parameter sensor-based device to measure air quality using the AQI index (including SO_2, NO_2, CO, O_3, and PM2.5). Meanwhile, Pham Van Khoa and Nguyen Van Thai [5] proposed a remote monitoring system applying IoT platforms, integrating temperature, humidity, PM2.5, and CO sensors.

Although previous studies have achieved significant results in monitoring air quality, most are limited to passive warning capabilities and lack integrated control mechanisms to optimize the in-vehicle microclimate. Therefore, this study focuses on designing and fabricating a multi-parameter measurement and warning system (air quality,

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temperature, and humidity) with automatic adjustment capabilities. The aim is to enhance user experience and ensure occupant health and safety. The findings not only contribute to solving the problem of in-cabin air pollution but also pave the way for the application of IoT and intelligent control technologies in the automotive sector.

II. IMPLEMENTATION SOLUTIONS

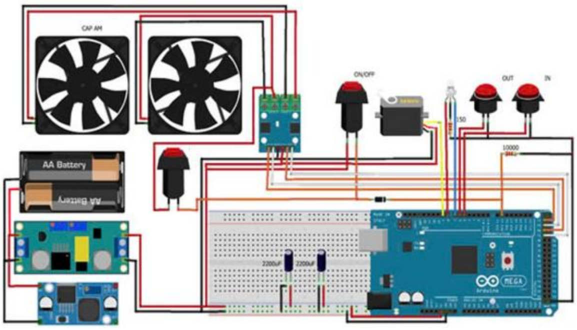

Figure 1. Circuit for measuring and warning air quality, temperature, and humidity inside a car, designed in the Fritzing environment.

The connection model of the components in the air quality, temperature, and humidity monitoring and warning system for automobiles was designed using Fritzing software, as illustrated in Figure 1. Sensors for CO_2, CO, dust, temperature, and humidity continuously collect data related to air quality inside the vehicle cabin. The Arduino Mega 2560 microcontroller processes the signals from these sensors. When any of the monitored parameters exceed safe thresholds, the system automatically activates actuators such as cooling fans, humidifiers, or ventilation outlets to improve air quality.
In addition, the system issues an audible warning and sends an SMS alert to the user. Real-time environmental data is also displayed on an LCD screen, enabling both the driver and passengers to monitor in-cabin air conditions and maintain health and comfort throughout the journey. The following sections will provide a detailed presentation of each system component and its operation.

2.1. Design and Fabrication of the CO_2 Concentration Measurement CircuitCác nghiên cứu trong nước:

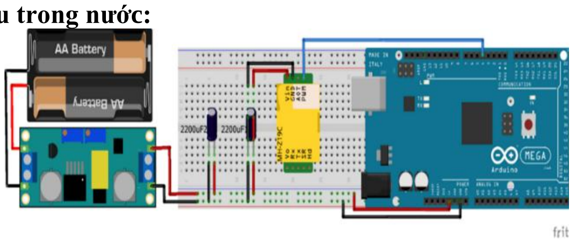

Figure 2. Arduino Mega 2560 circuit with MH-Z19C sensor module

The MH-Z19C sensor is a module for measuring CO2 concentration based on optical principles. When a 5V power supply is provided to the module, the sensor begins measuring the CO2 concentration in the vehicle's air and sends a PWM (Pulse Width Modulation) signal to the Arduino Mega 2560 microcontroller. This PWM signal contains information about the CO2 concentration in the air.The Arduino Mega uses a formula provided by the manufacturer to calculate the CO2 concentration value (in ppm):
ppmMHZ19 = 5000 * (th - 2) / (th + tl - 4)
Where th and tl are the durations of the high and low levels of the PWM signal. The constants 2 and 4 help eliminate errors caused by signal delay during the transition between high and low levels. When the CO2 concentration exceeds a safe threshold (e.g., 1000 ppm), the system activates an exhaust fan and opens the vehicle door to reduce the CO2 concentration in the air.

2.2. Temperature and humidity sensor circuit diagram

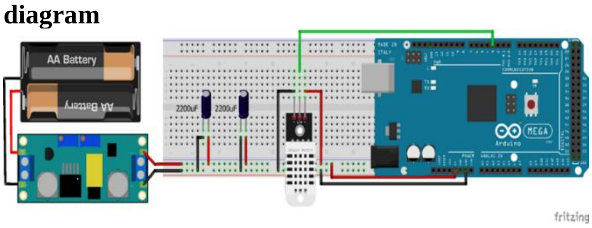

Figure 3. Arduino mega 2560 circuit DHT22 sensor

The DHT22 sensor is a commonly used device for measuring air temperature and humidity. It operates by collecting temperature and humidity data from the surrounding environment inside the vehicle and then transmitting this data as an electrical signal to the Arduino Mega 2560 for processing. The Arduino reads the values from the DHT22 sensor via a digital communication protocol and converts the signal into readable temperature and humidity values. These results are then displayed on the LCD screen, allowing real-time monitoring of the in-cabin environmental conditions.

2.3. Figure: Circuit diagram for CO gas concentration sensing

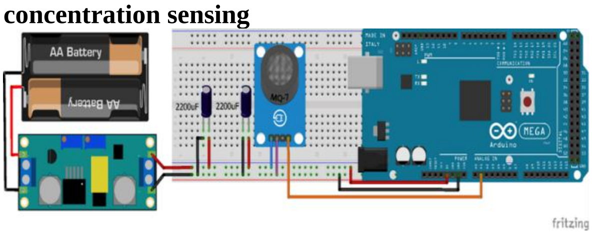

Figure 4. Arduino Mega 2560 circuit with MQ-7 gas sensor

The MQ-7 sensor is a semiconductor gas sensor used to measure the concentration of carbon monoxide (CO), a harmful gas present in the air. The

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sensor operates based on changes in its internal resistance when CO gas comes into contact with its surface. The MQ-7 outputs an analog signal to the Arduino Mega, where the signal is processed and converted to determine the CO concentration in the air. The Arduino then evaluates the concentration level inside the vehicle. If the CO concentration exceeds the permissible threshold (typically 50 ppm), the Arduino initiates a warning response, which includes activating an audio alert through the DFPlayer Mini module and sending an SMS notification via the SIM800C module to inform the user of the incident.

2.4. Circuit diagram of the dust sensor

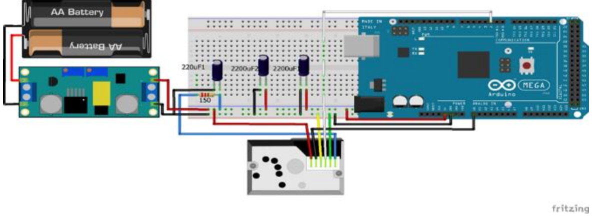

Figure 5. Arduino Mega 2560 circuit with GP2Y1010AU0F dust sensor.

The GP2Y1010AU0F sensor measures dust concentration in the air using optical sensing technology. It employs an internal LED light source and a photodetector to detect airborne dust particles. When dust is present, it reflects the light emitted by the LED, and the sensor converts the optical signal into an electrical signal. The Arduino Mega receives the analog output signal from the sensor through the V0 pin. It processes this signal to determine the dust concentration level in the cabin air. If the detected dust level exceeds the predefined safety threshold, the Arduino automatically activates a fan or air filter system to purify the air and maintain good air quality inside the vehicle.

The sensor requires two power inputs: a standard 5V supply (Vcc) and a separate power source for the internal LED (V-LED). A current-limiting resistor is used in series with the LED to prevent overcurrent and ensure its protection. The sensor sends the analog signal to the microcontroller via the V0 pin, and based on this input, the Arduino controls the LED switching through Digital Pin 2.

2.5. Circuit Diagram of the SIM800C Module

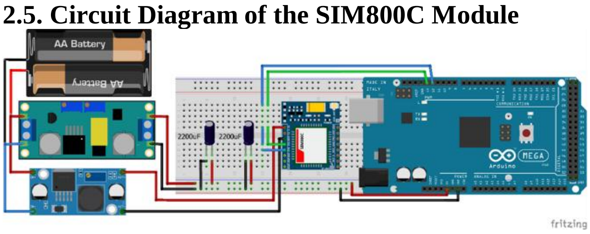

Figure 6. Arduino Mega 2560 circuit with SIM800C module.

When the circuit is powered on, the Arduino Mega sends a startup signal and checks the SIM card for the SIM module based on the code loaded onto the Arduino. This signal is transmitted from Digital Pin 13 (TX) to the RXD pin on the module (Figure 6). If the SIM module is functioning properly, it will send a response signal through the TXD pin back to Digital Pin 12 (RX) on the Arduino Mega. In summary, the microcontroller sends control signals to the SIM module through Digital Pin 13, the module executes the commands from the microcontroller, and then sends a "command executed" response back to Digital Pin 12 on the microcontroller.

2.6. Circuit Diagram of DFPlayer Mini Audio Playback Module

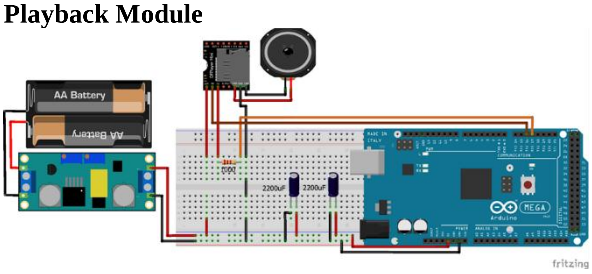

Figure 7. DFPlayer Mini audio playback circuit with speaker and Arduino Mega

The DFPlayer Mini module is used for playing warning sounds. ***Figure 7*** illustrates the circuit for audio playback using the DFPlayer Mini, a speaker, and the Arduino Mega, designed in Fritzing software. After the Arduino Mega processes signals from the sensors and detects air quality issues (such as high CO_2 concentration or excessive CO levels), it sends a control signal to the DFPlayer Mini. The Arduino Mega triggers the playback of warning audio files stored on the Micro SD card inside the DFPlayer Mini. These audio files can include reminders or warning sounds for the occupants of the vehicle. When an air quality issue occurs, the warning sound will be played, alerting the driver and passengers to take timely action.

2.7. Circuit Diagram of LCD Screen

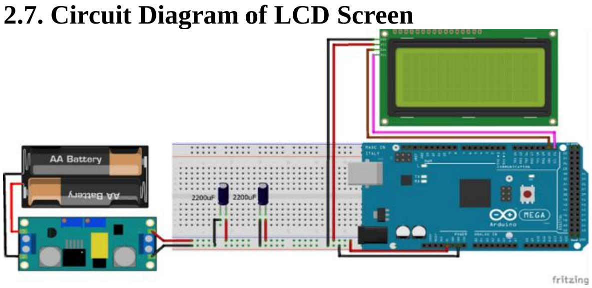

Figure 8. Wiring diagram of the LCD and Arduino Mega.

The LCD screen is used to display air quality parameters, including temperature, humidity, CO_2 concentration, CO levels, and dust concentration (Figure 8). The Arduino Mega communicates with the LCD via the SDA and SCL pins. It sends sensor data

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to the LCD, allowing users to monitor the air quality conditions inside the vehicle. Through the LCD display, users can easily observe and assess the air quality indicators and take appropriate actions to improve the in-cabin environment.

2.8. Power and actuator control circuit

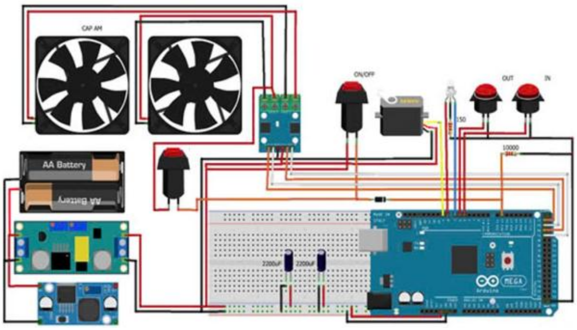

Figure 9. Actuator control system.

Figure 9 illustrates the control system for external air intake and automatic humidification, which is managed through signals from the Arduino Mega. These signals activate the fan or humidification system when the air quality parameters exceed predefined thresholds. The Arduino continuously checks the sensors and controls the fan or humidification system based on the programmed conditions. When the air quality is poor (e.g., high CO_2 or CO levels, low humidity, or excessive temperature), the system automatically activates the cooling fan and humidification to improve the cabin environment. **Figure 10** shows the completed system model.

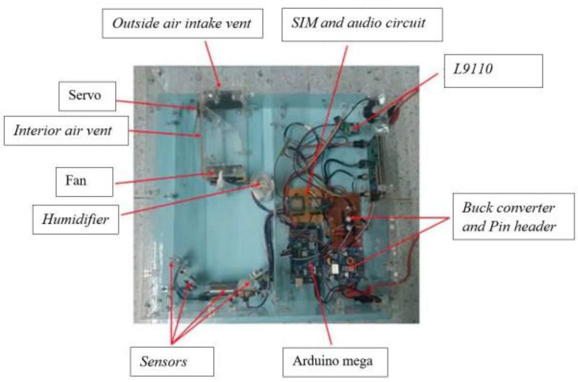

Figure 10. Complete system model.

III. TEST RESULTS AND DISCUSSION

3.1. Testing in an environment with permissible levels of air pollution, assuming a driver is present in the vehicle

By observing the LCD screen (Figure 11), the measured values from the sensors for CO, CO_2, dust, temperature, and humidity are all below the allowable threshold for each sensor. Therefore, the screen displays "Good+" or "Good." The LED on the screen is turned on to make it easier to read the displayed information. The results of the experiments are presented in **Table 1**. The experimental results show that the air quality measurement and warning system in the vehicle operates stably and provides reasonable and reliable results. Specifically, the measured values in different trials (CO, CO_2, dust, temperature, humidity) exhibit only slight variations, with CO fluctuating around 52–55 ppm, CO_2 ranging from 872–939 ppm, temperature from 30.9–31.7°C, and humidity between 71.4–72.8%. This also demonstrates that the system has good sensitivity and is minimally affected by noise.

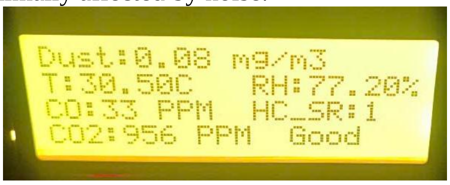

Figure 11. Sensor parameters displayed on the LCD.

Table 1. Parameters displayed by the system.

Parameter	First time	2nd time	3rd time	4th time	5th time	Mean
CO (PPM)	52	51	54	52	55	52,8
CO_2 (PPM)	956	872	922	925	914	914,4
Dust (mg/m^3)	0,08	0,04	0,05	0,08	0,6	0,06
Temperature (ºC)	31,7	31,7	30,9	31,2	31,0	31,3
Humidity (%)	71,4	71,4	72,8	72,0	72,5	72,02

3.2. The experiment from the exhaust emissions of a motorcycle with the assumption that there is a driver on the vehicle.

The LCD screen (Figure 12) displays the measured values from the sensors: CO, CO2, dust, temperature, and humidity in the air, which are all higher than the allowed values for each sensor (except for the dust sensor, as the exhaust system has filtered some of the dust, so the sensor only detects a slight increase, not exceeding the permissible threshold). The screen will display the word 'BAD'. The LED light on the screen remains on to make it easier to read the information displayed. The measured values over five trials are presented in Table 2. The CO (75.4 ppm), CO_2 (2190.6 ppm), and dust (0.156 mg/m^3) levels all show a clear increasing trend when exposed to the external pollution source, indicating that the system has high sensitivity and is minimally affected by noise. The temperature (31.88°C) and humidity (75.84%) remain stable across the measurements, confirming the system's ability to monitor continuously and accurately. This result meets the technical requirements and demonstrates that the system can provide timely warnings when air quality

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exceeds safe thresholds, ensuring the health and comfort of the driver.

Figure 12. Sensor parameters displayed on the LCD

Table 2. Measured sensor parameters

Parameter	First time	2nd time	3rd time	4th time	5th time	Mean
CO(PPM)	69	75	79	74	80	75,4
CO_2(PPM)	1791	2074	2378	2132	2578	2190,6
Dust (mg/m^3)	0,14	0,16	0,14	0,18	0,16	0,156
Temperature (°C)	31,9	31,8	31,8	32	31,9	31,88
Humidity (%)	75,6	75,8	76	75,9	75,9	75,84

3.3. In a polluted air environment and assuming there is no driver on the vehicle

When the switch is in the OFF position, the system is programmed to recognize that the passenger has left the vehicle. It will shut down all functions, including the LCD backlight, speaker, etc., in order to minimize power consumption from the vehicle's electrical system. Only the sensing system and the SIM module remain active.

Forgotten passenger function test: When the switch is OFF, if the CO_2 or CO concentration rises to a high level and the sensor detects the presence of a person, the system will automatically turn on the ventilation fan and switch to outside air intake mode. At the same time, it will send a message to a pre-set phone number to notify about the current situation (Figure 13). The results show that the system functions as intended.

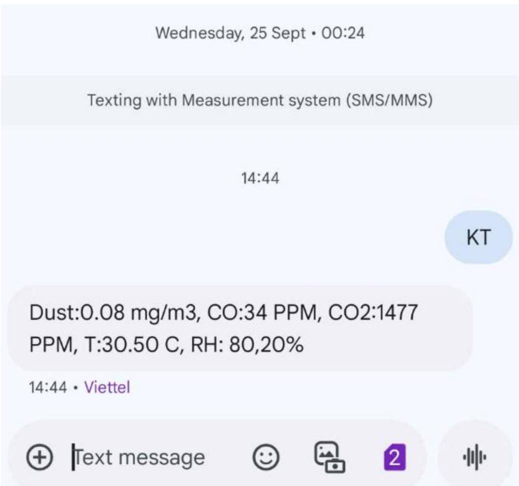

Figure 13. Warning message via SMS.

V. CONCLUDE

This study has successfully designed and developed a multi-parameter air quality monitoring system for automobiles, featuring several outstanding advantages. Firstly, the system achieves high accuracy and stability in measurement thanks to the integration of specialized sensors and an optimized calibration algorithm. Beyond basic monitoring, the system is equipped with multi-modal alert capabilities—through sound, visual indicators, and SMS notifications—when any parameter exceeds safety thresholds. It can also automatically activate response mechanisms such as ventilation or emergency alerts.

Notably, one of the study's most significant achievements is the successful development of a solution for detecting children left unattended in vehicles. This is accomplished through a mechanism that monitors CO_2 levels in combination with motion sensors, greatly enhancing safety for families with young children. Furthermore, the system incorporates IoT technology, enabling remote monitoring via SMS connectivity and paving the way for widespread adoption in modern smart vehicle systems.

From a scientific perspective, the study offers a new approach to in-vehicle microclimate control through comprehensive automation, effectively overcoming the limitations of previous passive monitoring systems. In terms of practical application, the system not only improves user experience but also significantly reduces health risks caused by air pollution—an especially important factor in the context of rapid urbanization.

To further advance this research, future directions should focus on upgrading the prediction algorithms using artificial intelligence, expanding applications to public transportation, and integrating additional toxic gas sensors for more comprehensive air quality assessment inside vehicles. The outcomes of this study lay a critical foundation for the development of advanced technologies in smart automotive systems and contribute to sustainable and effective public health protection.

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