Abstract— In recent years, vehicular emissions have emerged as a significant contributor to environmental pollution. Among the prominent culprits, carbon monoxide (CO) and nitrogen dioxide (NO₂) have garnered attention due to their association with gas-related poisoning incidents. Consequently, the imperative to monitor and promptly forewarn against hazardous gas levels within vehicle-centric environments like garages has become paramount. This study introduces an innovative solution: a gas measurement apparatus positioned within garage spaces, harnessing the potential of multi-sensor chips and Internet of Things (IoT) advancements. Employing a semiconducting metal oxide nanomaterial-based MICS-6814 gas sensor in conjunction with a DHT22 sensor for temperature and humidity, real-time data collection is facilitated through an ESP32 microcontroller. Transmission of these measurements to a cloud server is facilitated by a GSM/GPRS SIM800L module employing the MQTT protocol. Measured parameters are amenable to storage and display through a dedicated smartphone application. Testing at the laboratory confirms the device's reliability. The system allows facility managers to proactively identify hazardous gas concentrations and enforce targeted safety protocols within the garage environment.

Keywords—Gas detection, GSM/GPRS technology, IoT device, MICS-6814, SMO sensor.

I. INTRODUCTION

Over the last two decades, there has been a significant surge in road vehicle traffic, both on a global scale and specifically in Vietnam. This surge has brought with it a concerning rise in vehicle emissions, emerging as a prominent contributor to air pollution in numerous regions. Among these emissions, carbon monoxide (CO) and nitrogen dioxide (NO₂) take center stage as the primary gases generated during vehicle operation, posing significant health risks due to their potential for gas poisoning [1], [2]. Carbon monoxide (CO) is a colorless and odorless gas, making it imperceptible to the senses, thereby rendering its presence elusive to victims. On the other hand, nitrogen dioxide (NO₂) appears as a reddish-brown gas with an intensely pungent odor at higher concentrations. At lower levels, NO₂ remains both colorless and odorless but remains exceptionally toxic. Thus, the development of toxic gas monitoring equipment for CO and NO₂ becomes paramount, serving the dual purpose of ensuring the safety of vehicle occupants and enhancing overall road safety.

Many of the current gas measurement devices have relied on multiple single-gas sensors for detecting specific types of gases. Typically, these sensor boards were both bulky and had high power consumption. This research project endeavors to create a sophisticated toxic gas monitoring device for CO and NO₂, founded on the MiCS-6814 multi-gas sensor kit and Internet of Things (IoT) technology [3]–[5]. The sensor kit comprises compact metal oxide semiconductor (MOS) sensors with an operating power of under 100 milliwatts. These MOS sensors of the identical type function based on thermal fingerprint, exhibiting distinct responses to various gases [6]. In addition, IoT applications facilitate the connection of these monitoring devices to the Internet, enabling users to remotely monitor parameters and receive timely warnings [7], [8]. Measurement data can be securely stored on a cloud server, and accessible through a dedicated application on a computer or smartphone. This system's primary objective is to gauge
Integrating Multi-Sensor Chip and IoT Technology for Precise Monitoring of CO and NO₂ Gas Levels in Garage Environment

the concentration of toxic gases, as well as temperature and humidity levels, within various settings such as parking lots, basements, high-traffic zones, and even within vehicles themselves.

II. MONITORING DEVICE DESIGN

A. System block diagram and components

Figure 1 shows the block diagram of the main components of the measuring device. The design consists of a multi-sensor chip MICS-6814 of the MOS sensor family built with high sensitivity to CO and NO₂ gases; a DHT22 temperature and humidity sensor; an ESP32 WIFI board that allows connection and processing of data read from the sensor system to the data transmitter and LCD display; a GSM/GPRS SIM800L module that transmits data to a computer or smartphone using the MQTT protocol. The suggested components are compact, high precision, and are well-suited for deploying IoT applications. These modules of the device are operated when using the same 5 V DC power supply. Besides, Cloud Firestore is a versatile NoSQL database utilized in the development of mobile, and server applications within the Firebase and Google Cloud environment.

![Fig. 1. Block diagram of the gas levels monitoring system.](image)

B. Sensing calibration

Figure 2 shows the gas sensing board being placed in a gas mixing standard chamber at the Nanosensors Laboratory, at Phenikaa University. The main components of the measuring system include the gas mixing chamber, the devices and piping that control the flow of the gas through the chamber, the connection and signal transmission lines, and the interface to control the gas mixing process through software. LabVIEW. The parameters of airflow, gas concentration, temperature, and humidity in the gas mixing chamber are monitored automatically and continuously. The monitor was placed in a standard gas mixing chamber to perform a number of measurements with CO and NO₂ gases at a number of different concentrations (from 0.5 to 100 ppm for CO, and 0.05 to 5 ppm for NO₂). The measurement ranges tested align with both the sensor's detection capacity and the toxicity thresholds of the analyzed gases. The laboratory measurement data set was used to calibrate the device, thereby improving the accuracy of displaying the concentration of the measured gases.

III. IOT SYSTEM DESIGN

In this study, the Message Queuing Telemetry Transport (MQTT) protocol following the publish/subscribe model between devices was used. The MQTT brings many benefits, especially in monitoring control and data acquisition systems when accessing IoT data. Figure 3 shows the algorithm for transferring sensor data from the measuring device to the storage center using the SIM800L module and the MQTT protocol, and warns against exceeding the safe threshold of toxic gas concentrations. When the system starts working, some parameters need to be initialized. The system is then enabled to check the GSM/GPRS connections of the SIM800L module with the preset MQTT server. Next, the temperature, humidity, and concentration data for CO and NO₂ gases are read and compared with the previous data file (the initial data file is set by default). If there is a duplicate, the system waits for 1 second and then continues to read the data. If there are no duplicates, the new data file will be sent to the MQTT server, and stored with the timestamp taken.

![Fig. 3. Operation flow chart of the IoT application program.](image)
from the RTC DS1302 module, in a Cloud Firestore folder. Data on the concentration of gases continue to be checked to see if the threshold is exceeded or not. Otherwise, the system continues to read data from the device box. If there is a gas concentration parameter that exceeds the safe threshold, the system will send a message to the user's phone. After that, the system waits for 5 minutes to see the user's response. If the user response is received as processed, the system will continue to read and save the data. Conversely, the system sends a signal that activates the siren at the measuring device and stops the reading. Users are required to take safety measures at the gas measurement area, reset the measuring device, and then reactivate the remote monitoring system.

IV. RESULTS AND DISCUSSIONS

A. Measurement device

Figure 4 displays the circuit diagram of the measuring device (a), the printed circuit board image (b), and a photograph of a fully assembled monitoring equipment (b) enclosure with the dimensions 9.6 cm × 8.1 cm. The connections between the microcontroller pins and other important modules are shown. The designed circuit includes an additional real-time module RTC DS1302; and a small warning buzzer in place. The sensor kits, in conjunction with the LCD display screen, are securely affixed to the front panel of the enclosure. Inside the measurement box, you will find the microcontroller components and the SIM800L module safely housed. These compact units can be conveniently installed either within the basement parking areas of buildings or within vehicles.

B. Smartphone application

An application for smartphones has been developed using Google's MIT App Inventor to showcase temperature, humidity, CO, and NO₂ gas concentrations obtained from the monitoring device enclosure. The mobile application employs a straightforward software architecture known as Model-View-View Model, enabling the transmission of updates regarding parameters or status changes from the measuring device to the user. Upon launching the application and activating the power button, the app will indicate the connection status between the phone and the MQTT server. Table I outlines the five distinct connection states employed for this purpose. Once the connection is established and ready (Connection Status: 2), the user can simply tap the 'SUBSCRIBE' button, triggering the application's screen to exhibit the measurement parameter values, as illustrated in Figure 5. The measurement parameters, as shown on the LCD screen, are transmitted and faithfully displayed on the mobile phone application. Moreover, in cases where any of
the toxic gas measurement parameters surpass the safe threshold, the system can be configured to autonomously send a warning message to the user.

### TABLE I. SMARTPHONE APPLICATION AND THE MQTT SERVER.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Connection State</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Disconnected</td>
</tr>
<tr>
<td>1</td>
<td>Connecting</td>
</tr>
<tr>
<td>2</td>
<td>Connected</td>
</tr>
<tr>
<td>3</td>
<td>Disconnecting</td>
</tr>
<tr>
<td>4</td>
<td>Connection not supported</td>
</tr>
</tbody>
</table>

Table II provides details on the measuring device's capacity to detect gas concentrations, ambient temperature and humidity, and power consumption. The value ranges have been established based on the technical specifications of the sensors and experimental investigations conducted in the laboratory.

### TABLE II. OPERATING PARAMETERS OF THE DEVICE.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value/Range</th>
<th>Error</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO concentration</td>
<td>0.5 – 100</td>
<td>±0.1</td>
<td>ppm</td>
</tr>
<tr>
<td>NO₂ concentration</td>
<td>0.05 – 5.0</td>
<td>±0.01</td>
<td>ppm</td>
</tr>
<tr>
<td>Temperature</td>
<td>-30 – 80</td>
<td>±1.0</td>
<td>°C</td>
</tr>
<tr>
<td>Humidity</td>
<td>5 – 95</td>
<td>±5</td>
<td>%</td>
</tr>
<tr>
<td>Supply voltage</td>
<td>4.9 – 5.1</td>
<td>±0.1</td>
<td>V</td>
</tr>
<tr>
<td>Sensors power</td>
<td>85 – 200</td>
<td>±5</td>
<td>mW</td>
</tr>
</tbody>
</table>

The device has been installed and tested in various locations, including underground parking areas, parking lots, and inside vehicles. Figure 6 shows a result of parameters measured in a parking garage, displayed simultaneously on the LCD screen of the device box and the smartphone application. Measured parameters have been transmitted from the monitoring box and displayed accurately on the application software using IoT technology. The device can identify low concentrations of toxic gases of CO and NO₂. The device will continue to be researched and perfected to improve aesthetics and lower costs.

V. CONCLUSIONS

This research has achieved a significant milestone by designing and producing a monitoring device capable of tracking temperature, humidity, and the presence of hazardous gases, specifically CO and NO₂, employing a high-sensitivity and precise multi-gas sensor kit. The device boasts a compact form factor and minimal power consumption, making it an ideal choice for installation in various settings such as parking lots, basements, and vehicles. Measurement data is readily available for on-site viewing via the LCD screen, or it can be seamlessly transmitted to the Google Cloud Firestore storage center through the SIM800L module and MQTT protocol. Users can conveniently monitor these data points remotely using a dedicated smartphone application. Furthermore, the system incorporates early warning features to alert users when toxic gas concentrations exceed safe thresholds. Future research can further improve the device for testing in dynamic working environment conditions or assess the software's stability across various operating systems. The prospect of implementing artificial intelligence for data analysis and pattern recognition to enhance the intelligence and precision of monitoring equipment, as well as facilitating remote control over threshold warning systems, holds promise for future research endeavors in this field.

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REFERENCES


