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iJOE International Journal of Online and Biomedical Engineering

iJOE | eISSN: 2626-8493 | Vol. 19 No. 11 (2023) | OPEN ACCESS

https://doi.org/10.3991/ijoe.v19i11.41937

PAPER

Design and Fabrication of a Smart Monitoring System for Liquefied Petroleum Gas-Operated Cars Based on Global System Mobile

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ABSTRACT

In this paper, a low-cost smart system is designed and fabricated to monitor gas leakage in LPG-based cars. The implemented system consists of three gas sensors installed in the joints of the gas pipes, gas cylinders, and injectors for the purpose of gas leak monitoring. In addition, the LM 35 temperature sensor is situated over the gas cylinder to monitor its temperature. The implemented system can provide three types of alarm: the first type sends a text message to the car owner's phone and emits an audible alarm signal. The message reaches the service center also. The second type sends messages via Bluetooth to the user's phone or to the smart screen on the vehicle's dashboard, with an alert that the engine must be turned off (emergency case). The last warning sends an overheating alarm signal, utilizing a temperature sensor when the temperature of the gas cylinder exceeds 50°C to provide protection and prevent a possible explosion. In practice, it was found that gas sensors should be placed less than 5 cm from the monitored site, and the best performance at work was under 55°C. It was also found that the best performance of the GSM unit is under 55°C.

KEYWORDS

liquefied petroleum gas, global system mobile, Arduino, Bluetooth, gas sensor

1 INTRODUCTION

Natural gas represents one of the most important energy resources around the world, and a huge number of products also depend on it. However, the mixing of air and natural gas may result in explosive material. To overcome this threat, there are many studies to detect gases in different industrial environments. Most detect leaks at either wells for gas extraction, production and refinery sites, or infrastructure and distribution sites. There are many sensors for liquefied petroleum gas (LPG), such as the metal oxide semiconductor (MQ) family sensors, which mainly detect LPG gases by using

Salman, T.M., Abdullah, H.N., Marhoon, H.M., Karam, Z.A. (2023). Design and Fabrication of a Smart Monitoring System for Liquefied Petroleum Gas-Operated Cars Based on Global System Mobile. *International Journal of Online and Biomedical Engineering (iJOE)*, 19(11), pp. 96–111. https://doi.org/10.3991/ijoe.v19i11.41937

Article submitted 2023-04-02. Resubmitted 2023-05-12. Final acceptance 2023-05-14. Final version published as submitted by the authors.

Raspberry PI [1–3] and are programmed in the Python language. If data are sent with a value more than a threshold (reference value), the user is alerted and the sensor turns off the engine by closing the source of gas from the gas supply itself [4–8]. In another work, a system was designed to prevent fires and sense early gas leakage in homes An MQ-5 sensor was used for measuring LPG concentrations in the air by using a micro-controller in the home. It was used to monitor the gas system, and text messaging was used to alert the user with an alarm and activate a vacuum system [9, 10]. Internet of things (IoT) technology was used to detect and monitor the gas level using gas sensors and send gas-level data to the cloud via the IoT platform. The gas level is also analyzed periodically, and a daily alert notification is sent to the administrator via social media via smartphone if there is a gas leak in the house [11–13]. When surveying the previous works, it was noted that the proposed systems were directed to protect factories and buildings, but there were no previous works aimed at protecting and controlling gas systems in vehicles. Given that the gas systems that are installed consist of several parts and that these parts are subject to motion and changing forces, there is a high probability of gas leakage. This is because of long intervals between scheduled maintenance, the occurrence of accidents, and high gas pressure resulting from mechanical malfunction. Due to all these reasons, there is an urgent need to install a certified wireless sensor controller using IoT to detect the current state of a gas leak and send it immediately to the driver. This would help to avoid explosion accidents, since the system is located under the engine hood and is exposed to overheating, especially in hot weather. In the proposed safety system, four MQ-5 sensors and an LM35 temperature sensor are used, so that the gas sensors are distributed according to the location of the gas system. Two sensors are located under the engine hood to detect the gas leakage resulting from the gas injector and throttle valve. Another sensor is located at the contact point with the gas valve supply, which is divided into four injector throttle valves [14–18]. The last sensor is placed at the contact point with the cylinder head. Its function is to detect gas leaks in the system supply. The temperature sensor is placed directly on the gas cylinder to detect overheating of the cylinder to prevent high pressure and expansion as a result of heat. All sensors in the system are connected to the Arduino UNO and Nano controller. A global system for mobile communication (GSM) shield and Bluetooth are used to send text messages to the driver's phone and the maintenance center via SMS through an interactive interface on the phone designed in apk format to link with the system via Bluetooth. This interface can be installed on Android phones for the driver's phone or the vehicle's Android auto to appear directly [19–23].

2 PROPOSED SYSTEM METHODOLOGY

Figure 1 shows the LPG gas system operating in cars from the Swedish company Volvo, which will be considered as a model to illustrate the proposed gas leak detection and warning system. It consists of main and auxiliary fuel cylinders with a gas filling and pumping system. The main cylinder can fill up to 200 bar of gas pressure.

The system consists of copper pipes and plug connections to join electrically between the gas cylinder and the distribution system. It also includes the other pumping parts of the engine, which contains a gas distributor, connected to the pipes coming from the distribution system attached to the rear cylinder, where the gas is then distributed by injectors. The number of sensors attached increases according to the number of gas injectors that inject gas directly into the throttle body. The gas regulator controls the pressure in the fuel injector and distributes it equally between them. Gas-powered cars currently operate on a dual system that uses gasoline and LPG or

NPG fuels. As shown in Figure 1, the system consists of a dual tank for gasoline and alternative fuels. In the event of any defect in the gas system or gas depletion, there is an electronic circuit (powertrain control model) that controls this through a key equipped in the instrument panel in front of the driver for converting the choice between the two fuel systems used: gasoline or gas. The designed gas leakage detection and warning system consists of two units. These are a gas-detecting unit equipped with the engine (GDUEE) and a central control unit for gas detection and alert transmission (CCUGDAT). The circuit diagram of a GDUEE unit is shown in Figure 2.

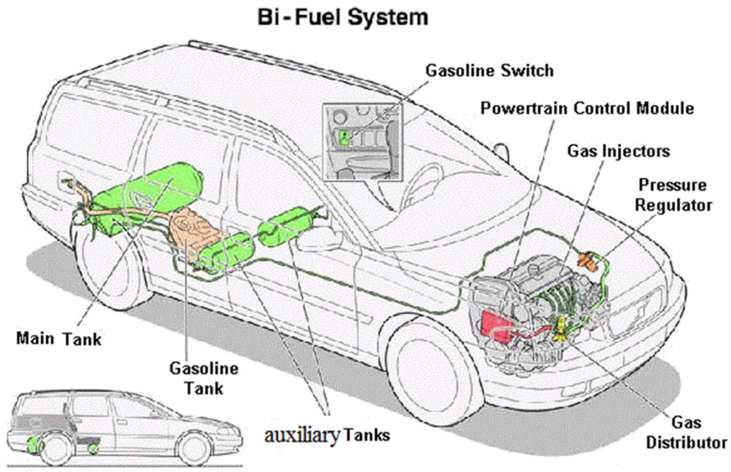

Fig. 1. Functional parts for LPG-based cars [6]

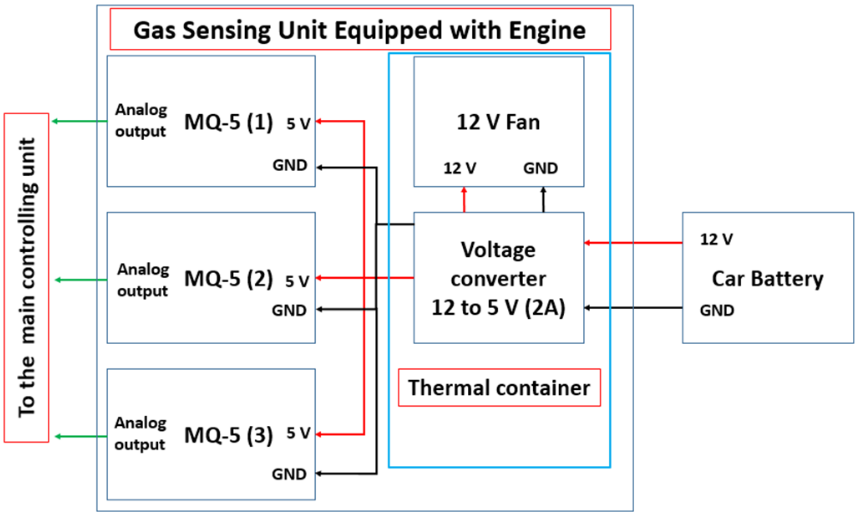

Fig. 2. Circuit diagram of the sensor system attached to the motor

This unit consists of a DC voltage converter, shown in Figure 3, whose function is to convert the voltage from the car battery of 12 volts to 5 volts to provide the required operating voltage to the sensors [24, 25]. Three MQ-5 sensors, shown in Figure 4, are used for gas leakage sensing. Two of them are used to sense gas leakage from the fuel injector in the cylinder head from the engine body, while the third is mounted on the gas regulator to sense gas leakage from it. The MQ-5 sensor type was chosen to sense LPG gas due to its ability to sense gas with a high accuracy over a wide range extending from 200 to 10,000 parts per million [26]. Table 1 compares the MQ-5 sensor with other gas sensors.

Fig. 3. A step-down voltage converter from 12 to 5 volts

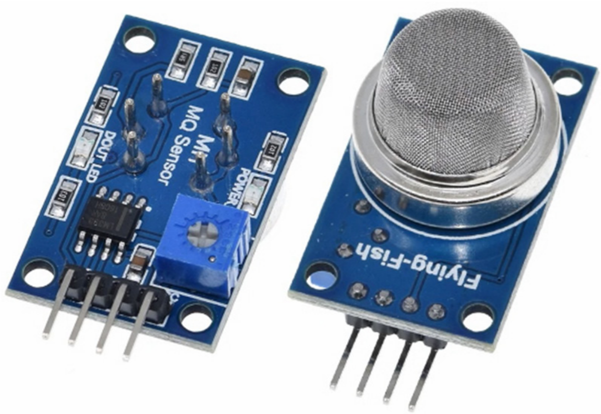

Fig. 4. LPG gas sensor type MQ-5

A GDUEE unit is placed under the hood of the car with a voltage regulator placed in a heat box and equipped with a fan to cool the regulator that feeds the three sensors with the required voltage, as shown in the diagram in Figure 2. Special aluminum containers lined with thermal insulating foam have been designed to protect gas sensors from engine heat, as shown by the diagram in Figure 5. Placing the injector sensors, pressure-regulator sensor, and cylinder-head sensor inside these containers also contributes to collecting and applying gas on the sensors to prevent leaks to the rest of the engine parts and the outside air, which would result in risks.

Table 1. Existing gas sensor measurement ranges [27, 28]

GAS	Range	Product Name	SKU
	200–10,000 ppm	Grove – Gas Sensor (MQ2)	101020055
	0.05–10 ppm	Grove – Gas Sensor (MQ3)	101020006
CO	200–10,000 ppm	Grove – Gas Sensor (MQ5)	101020056
	20–2000 ppm	Grove – Gas Sensor (MQ9)	101020045
	0–1000 ppm	Grove – Multichannel Gas Sensor	101020088
	200–10,000 ppm	Grove – Gas Sensor (MQ5)	101020056
	100 ppm–2000 ppm	Grove – Gas Sensor (MQ2)	101020055

(Continued)

Table 1. Existing gas sensor measurement ranges [27, 28] *(Continued)*

GAS	Range	Product Name	SKU
Alcohol	10–500 ppm	Grove – Multichannel Gas Sensor	101020088
	20–1000 ppm	Grove – Alcohol Sensor	101020044
	0.05–10 ppm	Grove – Gas Sensor (MQ3)	101020006
O_2	0–25% VOL (0–250,000 ppm)	Grove – Gas Sensor (Or)	101020002
	200–10,000 ppm	Grove – Gas Sensor (MQ5)	101020056
	5000–20,000 ppm	Grove – Gas Sensor (MQ2)	101020055
CH_4	500–10,000 ppm	Grove – Gas Sensor (MQ9)	101020045
	>1000 ppm	Grove – Multichannel Gas Sensor	101020088
	0.05–10 ppm	Grove – Gas Sensor (MQ3)	101020006
	200–10,000 ppm	Grove – Gas Sensor (MQ5)	101020056
	200–5000 ppm	Grove – Gas Sensor (MQ2)	101020055
LPG	500–10,000 ppm	Grove – Gas Sensor (MQ9)	101020045
	0.05–10 ppm	Grove – Gas Sensor (MQ3)	101020006
	300–5000 ppm	Grove – Gas Sensor (MQ2)	101020055
H_2	1–1000 ppm	Grove – Multichannel Gas Sensor	101020088
	200–10,000 ppm	Grove – Gas Sensor (MQ5)	101020056
Smoke	200–10,000 ppm	Grove – Gas Sensor (MQ2)	101020055
NO_2	0.05–10 ppm	Grove – Multichannel Gas Sensor	101020088
NH_3	1–500 ppm	Grove – Multichannel Gas Sensor	101020088

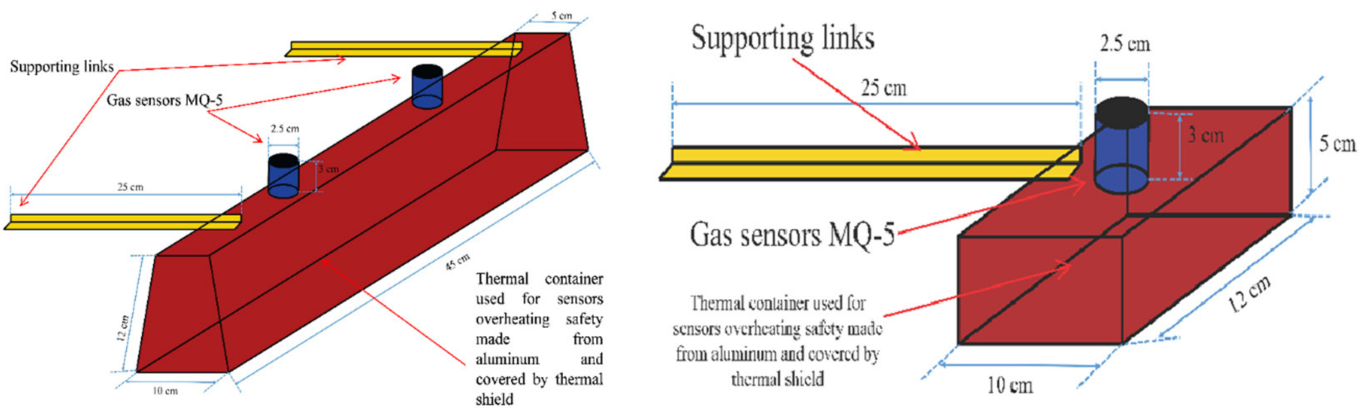

Fig. 5. Diagram of the containers designed for the sensors proposed in this work

The second unit (CCUGDAT unit) is responsible of controlling the gas detection process and transmitting alerts. The circuit diagram of this unit is shown in Figure 6. Hardware components for the proposed system are shown in Figure 7. A step-down regulator unit consists of a step-down regulator from 12 volts (supplied from the car battery) to 7 volts to operate the control cards, as shown in Figure 7a. The Arduino UNO (Figure 7b) was used to exploit its ability to attach with the GSM 900 Arduino Shield accessory card (Figure 7c), which includes the prepaid SIM card used. The circuit also includes the Bluetooth module transmitter, (Figure 7d) and the temperature sensor (LM 35) used (Figure 7e). The main circuit also includes Arduino UNO and Nano microcontrollers, as shown in Figure 8, which allows the possibility of receiving notifications for phones running the Android operating system, where an application designed specifically for this purpose is installed in the phone of the driver. The Bluetooth transmitter can connect to the car's Android auto software and receive messages through it. The aim of adding Bluetooth is to have a backup transmitter unit to send signals to notify the driver whenever the GSM unit stops.

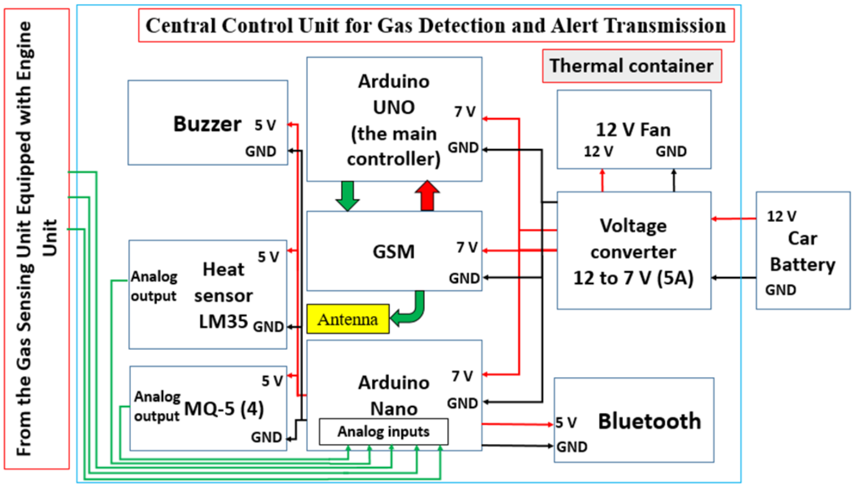

Fig. 6. Circuit diagram of the main control unit for gas sensing and sending notifications from the car's gas tank

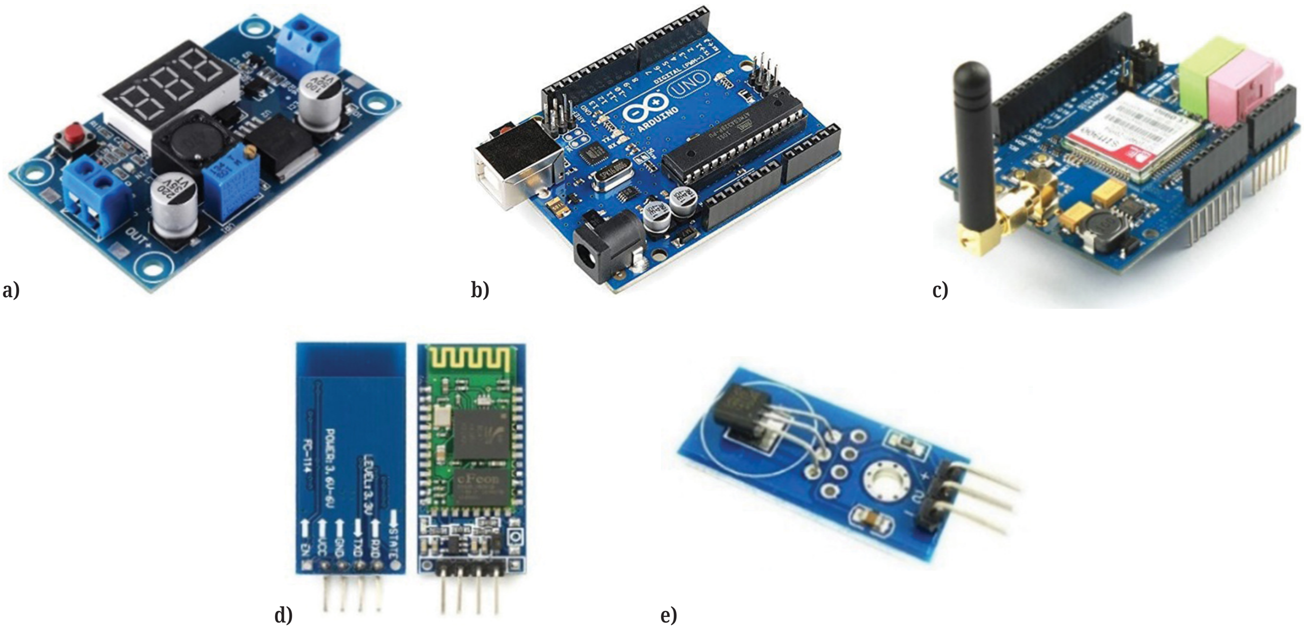

Fig. 7. Hardware components for the proposed system: (a) step-down regulator from 12 to 7 volts, (b) Arduino UNO, (c) GSM shield SIM 900, (d) Bluetooth module, and (e) LM 35 temperature sensor

This system also contains a temperature sensor of the type LM35, which is attached to the gas cylinder. If the temperature exceeds 50°C, the sensor sends a signal to the device to send a warning message to the driver about an increase in the temperature of the gas tank. As for the Nano-type control card, it is used to receive all sensor signals (four gas sensors and one temperature sensor) and sends the sensor signal to the main controller, Arduino UNO. Figure 8 depicts the circuit diagram of the complete electronic circuit of the gas-sensing system for vehicles.

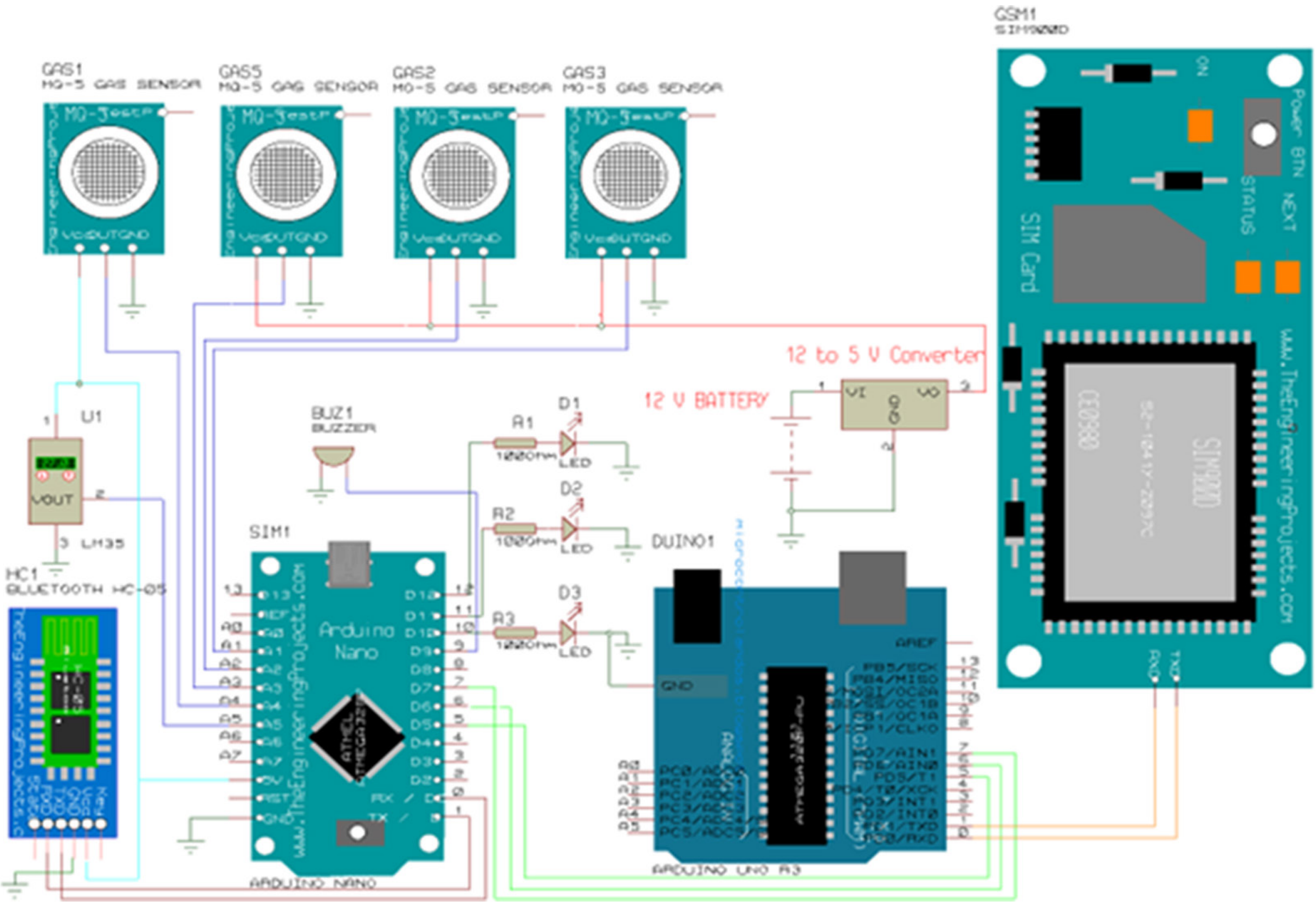

Fig. 8. Complete electronic circuit of the gas-sensing system for vehicles

3 RESULTS AND DISCUSSION

In this section, the design flow of the proposed system described in the previous section—as well as examples of alarm messages produced upon practical testing—are presented. The operation is explained in the following steps:

a) The Arduino Nano microcontroller reads the measurements of the four MQ-5 sensors (from the three sensors in the front circuit and the one in the rear circuit with the gas tank) and the reading of the temperature sensor LM35 is measured using analog input pins (A1, A2, A3, and A4) where the internal resistance of the sensors changes. By changing their values, the controller detects these analog inputs with a sensitivity range of 0–1023 bits [29].

b) After reading the sensor value, the Nano sends the sensitivity values to the UNO, which acts as the main controller in the circuit, according to the model of the controller shown in the flowchart in Figure 9. The received warning SMS for any gas leaks or overheating is shown in Figure 10. The received notifications for the programmed app messages via Bluetooth to the driver's phone are shown in Figure 11.

c) The UNO controller operates a buzzer, with an audible frequency in case of any gas leakage or system overheating from any sensor.

d) The UNO controller also turns on special LEDs with each sensor to visually indicate the work of the system elements. These lights give the driver a quick indication when inspecting the system about the type of the problem if no messages reach him via GSM or Bluetooth.

e) The fans' ventilators attached to the thermal boxes containing the electronic components will turn off 15 minutes after the car is turned off, after the engine temperature has stabilized and dropped, by a signal from the controller in the circuit (2) to conserve the energy of the car battery.

Figure 12 shows sensors power feeding circuit, and Figure 13 shows the implementation of gas sensors embedded in mechanical containers designed for this purpose. Figure 14 shows implementation of an electronic circuit with the sensing control circuits. The circuit design with the sensing control elements is shown in Figure 15.

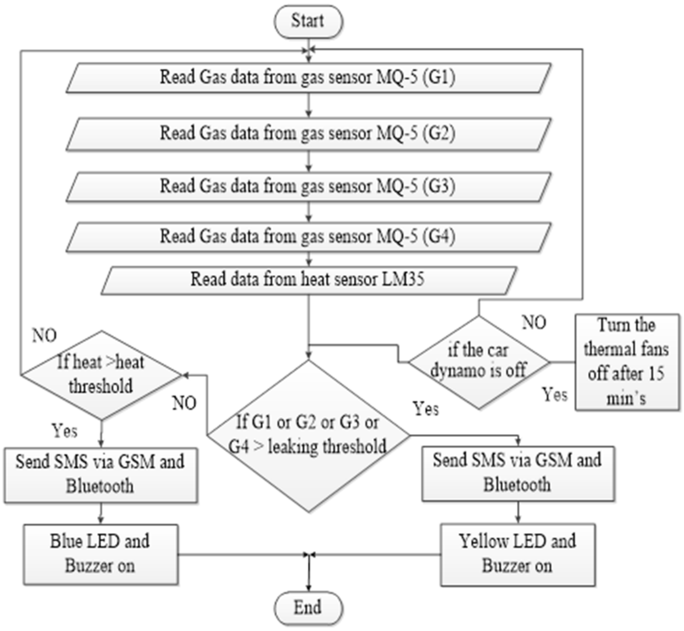

Fig. 9. The control algorithm of the gas-sensing system

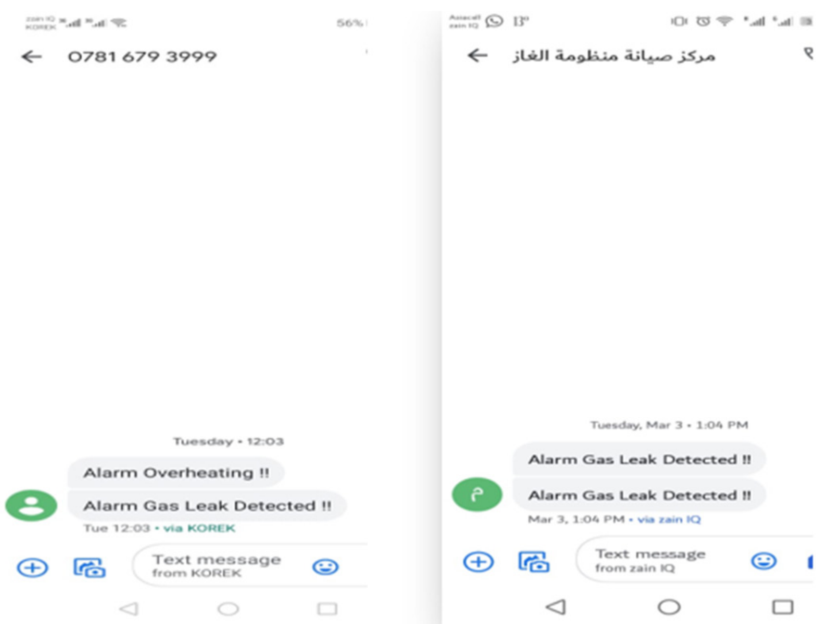

Fig. 10. Received warning SMS for cases of gas leaks or overheating

Fig. 11. Received notifications for the programmed app via the Bluetooth to the driver's phone

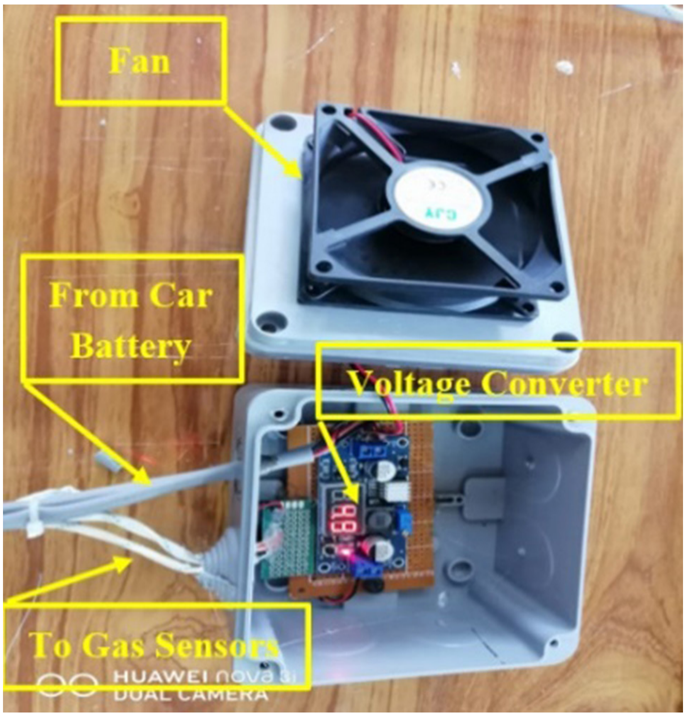

Fig. 12. Sensors' power-feeding circuit

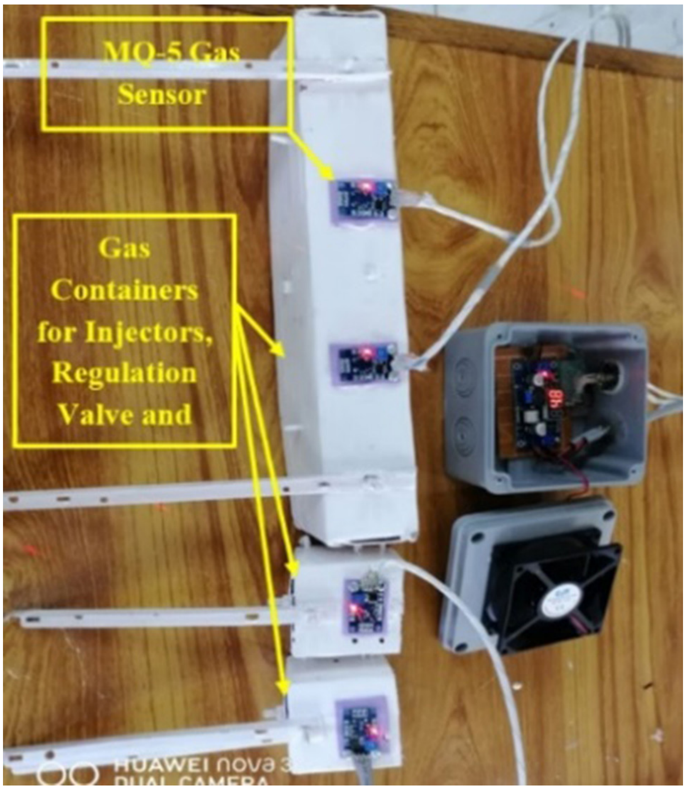

Fig. 13. Gas sensors embedded in the designed mechanical containers

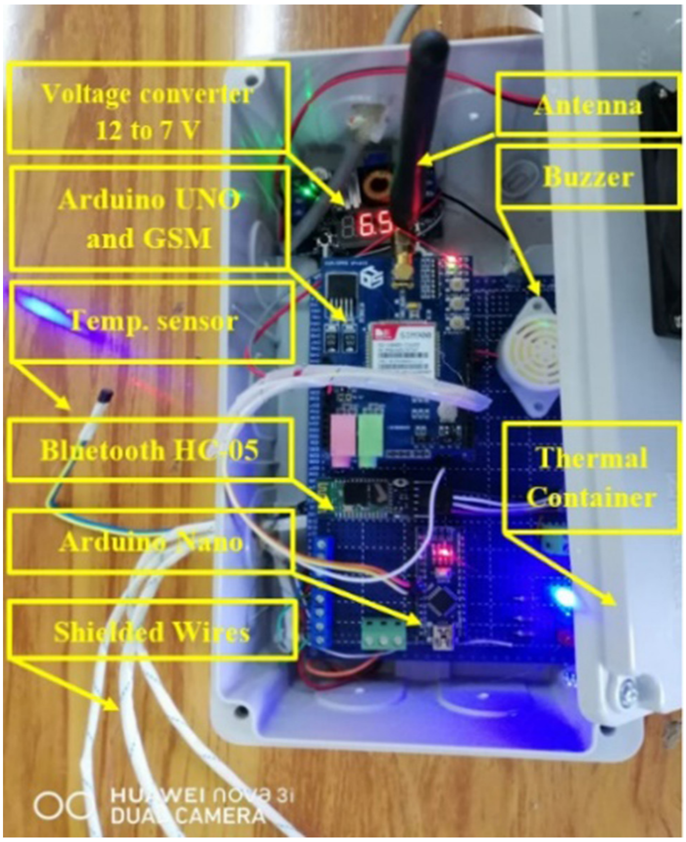

Fig. 14. The designed electronic circuit with the sensing-control circuits

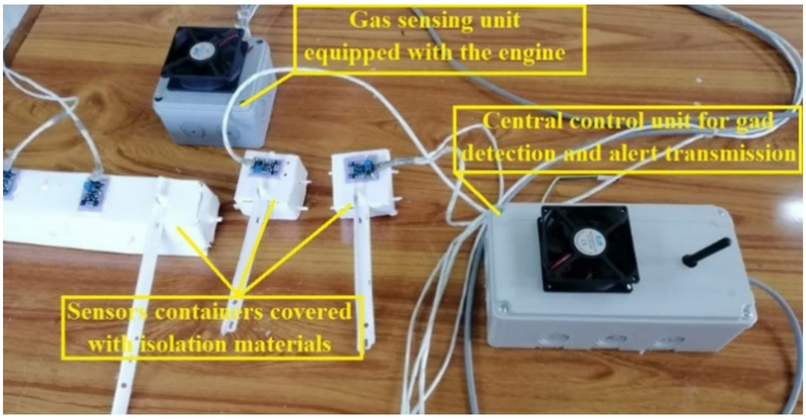

Fig. 15. The designed electronic circuit with the actual sensing-control elements

3.1 Features of the proposed system

The proposed gas leak monitoring and warning system has features that are summarized as follows:

a) The designed system senses gas leakage and system overheating in the gas tank of the gas-fueled car and sends a text message to the user's phone and to the maintenance center at the same time to protect against accidents.
b) Messages can also be received via Bluetooth through a special application designed and installed on the user's phone or on the smart screen on the dashboard of the car's smart applications in case no balance on the GSM or a mobile network signal is not detected.
c) Alerts the driver by keeping the buzzer ringing until the cause of the alarm is removed.
d) The system continues to operate in case of a gas leak, even after the car is turned off, where it the operates using the car's battery. The rated current does not exceed 100 mA [30, 31], which allows operators to know the conditions of the car's gas system even after parking for several days.
e) The cooling fans of the electric circuits are turned off by an internal timer after 15 minutes of turning off the car battery charger and engine.
f) The GSM shield is connected with an individual Arduino board (because this shield requires a stable feeding current [32, 33]).
g) In Figure 16, the effect of changing the distance between the MQ5 sensor and the parts (cylinder, pipeline, and injector) was examined. It was found that to obtain the best sensitivity of the equipment, the sensor should be placed at a distance of 1–2 cm.
h) In Figure 17, the distance from the MQ5 was fixed at 1 cm, and the change in the external temperature (which affects the sensor group) was increased from 20°C to 60°C. It was found that the best working range was below 50°C, and the best performance of the sensor at high temperatures is close to the cylinder, because it is better protected from the influence of the external temperature.
i) In Figure 18, the effect of overheating on the time delay in receiving a warning SMS messages from the GSM module was examined. It was found that the delay time is directly proportional to the temperature rise, and the operation of the device is stable at temperatures from 0 to 50°C.

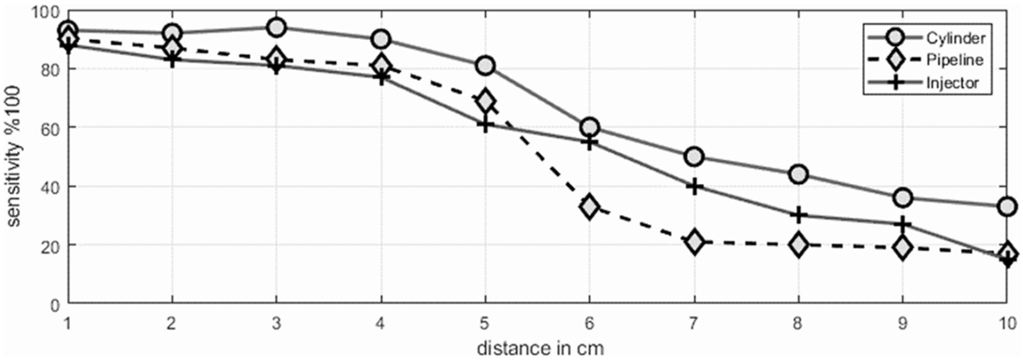

Fig. 16. Relationship between distance and sensitivity of MQ5

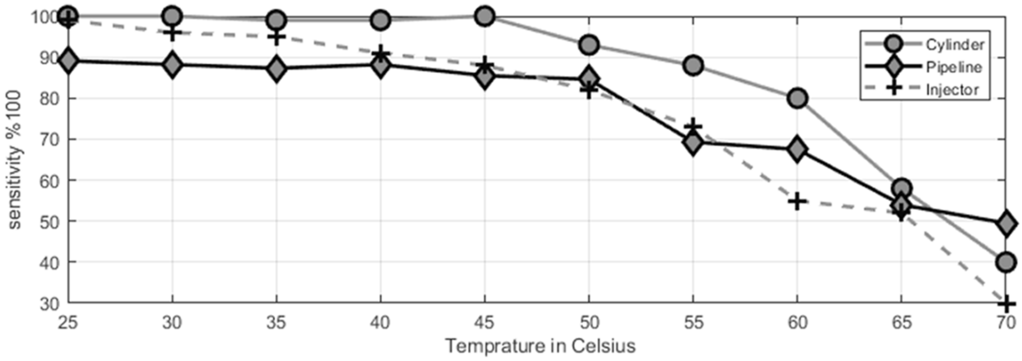

Fig. 17. Relationship between temperature and sensitivity of MQ5

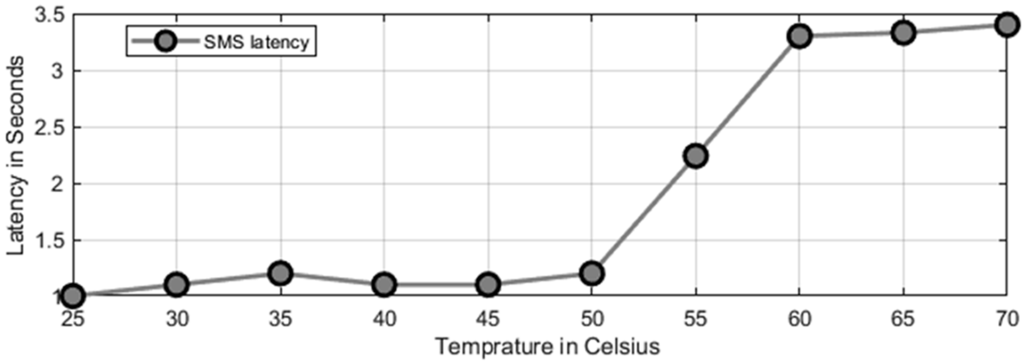

Fig. 18. The effect of overheating on the operation of the GSM

4 CONCLUSION

In this work, a smart LPG-based car system was designed, fabricated, and examined. The main purpose of the system was to monitor LPG leaks and overheating of the gas cylinder. The proposed system was tested by applying LPG gas to the MQ-5 sensors according to the calibration that was applied in the lab. The detection process was carried out successfully such that the sensors detected the gas and sent text messages to the driver's phone installed in the GSM chip from the Telecom provider. Text messages were received periodically every 1 minute for two virtual phones—the driver and the service center's—at the same time. The messages were sent via the Arduino monitor application, which was specially programmed to work with this system. It was installed on the driver's mobile device and the smart screen on the car's dashboard via Bluetooth Hc-05. Alarm text messages continued to be received in both cases until the effect of the gas was removed. The system was also tested in sensing the temperature through the LM35 sensor, and the sensor messages were successfully received when the temperature exceeded 50°C. The alarm buzzer was also tested to warn the driver—in case of forgetting the phone or turning it off—for all alerts except for in the case of ending the cause of the event. As a last and simple protection, LED lights were added to show the status of the system and the type of alarm, with a warning indication on the front.

5 ACKNOWLEDGMENTS

The authors want to pay their appreciation and thanks to Mustansiriyah University, Al-Nahrain University, and Al-Esraa University for their encouragement with this research.

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