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Intelligent Vehicle Gas and Fire Detection and Suppression System

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Abstract: The increasing complexity of vehicle electronics and conventional fuel systems have elevated the risks of gas leaks and fires. In addition, high-density batteries in Electric Vehicles (EVs) raises the risk of fire. Vehicle fires represent a significant safety hazard, causing hundreds of deaths and billions in property damage annually. One of the main dangers related with firefighting operations is the harmful ambience resulted from combusting materials. The four main hazards related to these cases are smoke, the oxygen insufficient atmosphere, high temperatures, and toxic ambience. Hence, fire is a real danger and fire safety is a critical issue in vehicle's industry. This paper proposes a real-time intelligent vehicle gas and fire detection and suppression system. The system uses Arduino Microcontroller based-system that integrates multi-sensor data fusion capable of detecting gas, smoke, over-temperature and combustion. The system uses alarm signaling devices, solenoid valve, fire-extinguishing equipment, and feeders for the fire-extinguishing substance. This comprehensive vehicle safety system provides multi-layered protection against gas leaks, fires, and overheating and automatic response without driver intervention. Hence, it is capable of detecting and suppressing fire. In addition, the system is interfaced to GSM network to enable wireless communication through SMS.

Keywords: Vehicle safety, Fire detection, Gas leak detection, Arduino microcontroller

Introduction

Fires represent a serious threat to humans, property, and the environment. It is a disaster that threatens people's lives and properties including vehicles (Saraev, 2025). Timely detection and effective extinguishing are essential to reduce harmful consequences. Vehicles' fires in transportation occur regularly. In recent years a significant number of severe fires in vehicle depots have occurred, mostly resulting in the loss of a larger number of vehicles (Hofmann et al., 2025). Vehicle fires are among the most severe risks faced by transportation industries. From buses carrying passengers to small private cars, fire outbreaks can result in catastrophic losses of lives and properties. There are several reasons for vehicle fires such as fuel leakage, engine overheating, and electrical short circuits. Another reason is where a vehicle caught in an accident. If the fire is not suppressed in time, the driver and his company and the vehicle would be in big threat. Sometimes, it is difficult to suppress a fire in a vehicle using hand fire extinguisher because of the fierce fire. In addition, fires in electrical vehicles pose significant safety concerns in modern vehicle systems (Mishra et al., 2025).

Recently, Lithium-Ion Batteries (LIB) are increasingly used in devices people interact with daily. They are found in several instruments such as smartphones, laptops and vehicles. However, they possess significant

safety risks, especially regarding fires. The probability of LIB to over-heat or even to catch on fire increases when incorrectly charged or used (Scarfogliero et al., 2018).

As people use electric vehicles (EVs), LIB technology has a major role in the vehicle because of its characteristics such as power. However, the age and the expected lifetime of the LIB are still under study and investigation. LIB aging is affected by several factors such as temperature and current rate (Scarfogliero et al., 2018). Hence, these batteries are responsible for an increasing number of fire incidents. For example, LIB operates best between 15°C and 45°C. low temperatures (<15°C) have a risk of lithium dendrite forming which can cause short circuits. High Temperatures (>40°C) can lead to releasing flammable gases and increasing explosion risks (Tai et al., 2024).

Researchers are constantly putting efforts into developing better and more reliable automatic vehicle fire suppression methods and technologies to provide the market with safer vehicles. This paper proposes the design and rationale for an intelligent vehicle gas and fire detection and suppression system. The system uses Arduino Microcontroller based-system that integrates multi-sensor data fusion capable of detecting gas, smoke, over-temperature and combustion. The system uses alarm signaling devices, solenoid valve, relay, fire-extinguishing equipment, and feeders for the fire-extinguishing substance. Hence, the system is capable of detecting and suppressing fire. In addition, the system is interfaced to Global System for Mobile Communications (GSM) network to enable wireless communication through Short Message Service (SMS).

Proposed System

Vehicles' fires in transportation occur regularly. Timely detection and effective suppressing are essential to reduce harmful consequences. In this paper, we propose an intelligent vehicle gas detection and suppression system using Arduino Microcontroller. The system integrates various sensors to detect gas, smoke, over-temperature, flames, combustion and extinguish fire in the vehicle. The Arduino Microcontroller is the brain of the system. The system includes in addition to the Arduino, MQ2 gas/smoke sensor, REES52 IR flame sensor, LM35 temperature sensor, buzzer, relay, solenoid valve, water pump, SG90 servo motor, Light Emitting Diode (LED), Liquid Crystal Display (LCD), and GSM. Fire safety is ensured through flame and gas sensors, triggering immediate alerts. The suppression system utilizes relay, solenoid valve and a spray nozzle system. The block diagram of the proposed intelligent safety system is shown in Figure 1.

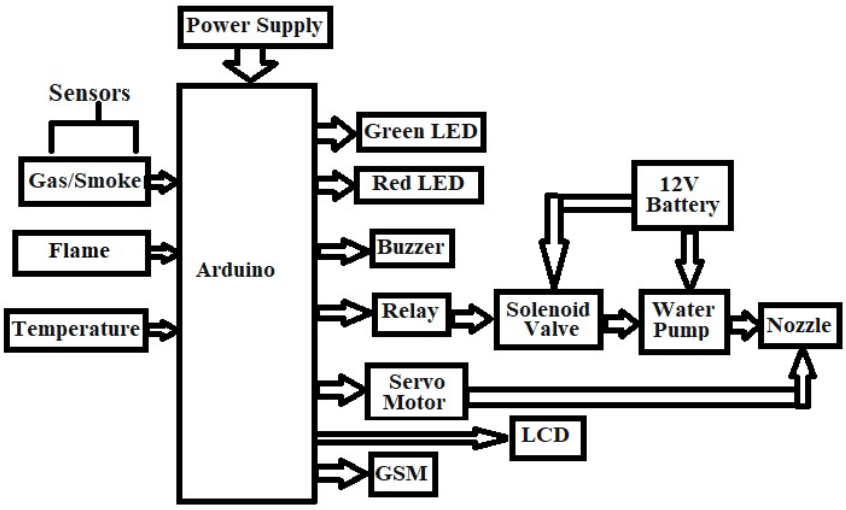

Figure 1. Block diagram of the proposed intelligent vehicle safety system

The major components of the proposed intelligent fire and gas detection system in the block diagram are described here.

Arduino Microcontroller

"Arduino microcontroller is an open-source board used to design and build electronic circuits. It is a low-cost device and is easy-to-use hardware and software" (Al-Smadi et al., 2020). Arduino board has digital and analog

inputs' and outputs' pins. Arduino board can read inputs from sensors and instruments, turn them into output commands that can activate other parts such as LED. Figure 2 displays an Arduino microcontroller board.

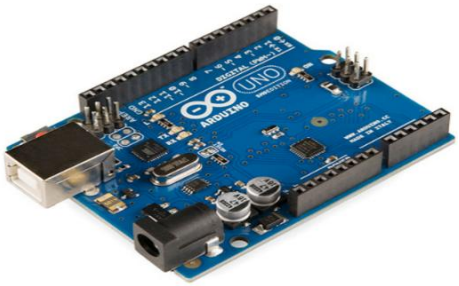

Figure 2. Arduino microcontroller (Al-Smadi et al., 2020)

MQ2 Gas/Smoke Sensor

MQ2 gas/smoke sensor used for detecting the concentration (leakage) of smoke and various gases in the atmosphere such as liquefied petroleum gas (LPG), methane, carbon monoxide and propane (Babu et al., 2024, Wang et al. 2023). It contains a small heater with an electrochemical part to measure different kind of gases. MQ2 sensor has a sensing material whose resistance changes with the type of gas in the atmosphere. That is, when one type of gas touches the sensor after heating, the sensor's resistances change. Hence, the voltage across the sensor changes which will be read by the Arduino Microcontroller. This sensor is used to detect the leakage of harmful gases. It has an analog output signal which can be read by the Arduino analog input. The MQ2 gas/smoke detector is shown in Figure 3.

Figure. 3. MQ2 gas sensor pinout

REES52 IR Flame Sensor

The REES52 infrared (IR) flame sensor is a vital component for fire detection and safety systems (Al-Smadi et al., 2024). This specialized module employs an infrared sensor to detect the presence of flames. The IR Flame Sensor for Arduino is a highly sensitive sensor that can detect the presence of IR radiation emitted by flame. It converts this detection into a digital voltage signal. It is convenient to use with the Arduino microcontroller and can be integrated into a wide diversity of applications such as fire detection systems and home security. The REES52 IR flame sensor is shown in Figure 4.

Figure 4. REES52 IR flame sensor

LM35 Temperature Sensor

This sensor is realized for its precision in temperature measurement when the output voltage is linearly proportional to the Celsius, °C, temperature (Shuvu & Chowdhury, 2024). It is designed with no need for further calibration, so it can be used where simple and accurate temperature tracking is recorded. The output scale factor of the LM35 temperature sensor is 10 mV/°C. Hence, to calculate the temperature, the voltage (mv) in output pin is divided by 10. The range of temperature that the sensor can measure is from -55°C to 150°C. The pin diagram for the LM35 sensor is shown in Figure 5.

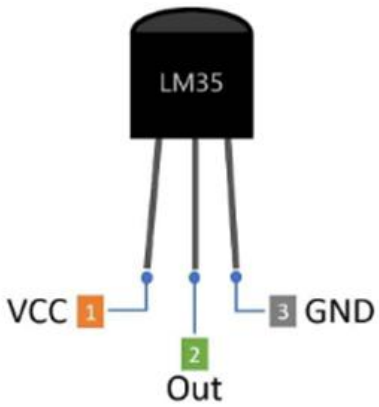

Figure 5. LM35 sensor pin diagram

Actuation Unit

The SG90 is a servo motor used to rotate an object to a particular angle or position. The angle of the servo motor is controlled by the Arduino. It has three wires: power, ground and signal. The servo is low power controlled by Pulse Width Modulation (PWM) signal, with a duty cycle of 600µs to 2400µs (measured), and a total period of 20ms (50Hz) (Al-Smadi et al., 2026). The Arduino generates the PWM signals to make the servo motor work. Figure 6 shows the SG90 Servo Motor pinout. Servo motor can make rotation about 180º (90º in each direction).

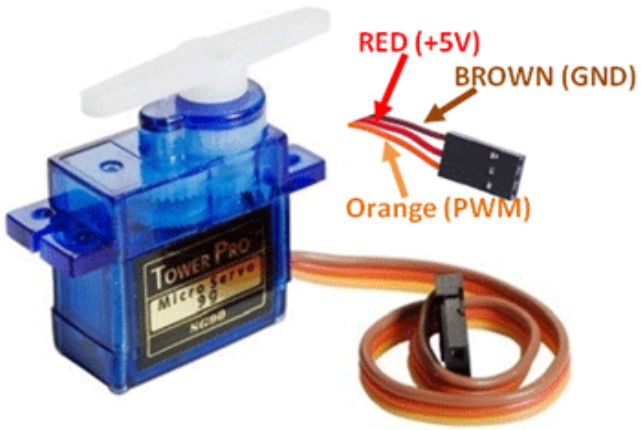

Figure 6. SG90 servo motor pinout

Solenoid Valve

The solenoid converts electrical signals into mechanical motion. A water solenoid valve is an electromechanical device that controls and regulates the flow of water by opening (or closing) in response to an electric current (Fan, 2025). A solenoid valve consists of three main components: a solenoid (an electric coil), a plunger (or armature), and a valve body. As an electric current goes through the solenoid, it generates a magnetic field that moves the plunger within the coil, allowing or stopping the flow of water. Water solenoid valves play a significant role in handling water flow in different applications. A water solenoid valve is shown in Figure 7.

Figure 7. Water solenoid valve

Relay

A relay is an electrically operated switch. As an electrical current goes through the coil, it generates a magnetic field that activates the contacts (armature which connects or disconnects the circuit). Hence, a relay is a switch that is used to turn on and off electrical circuits in response to a low-current control signal (Al-Smadi et al., 2019). Figure 8 shows a typical relay.

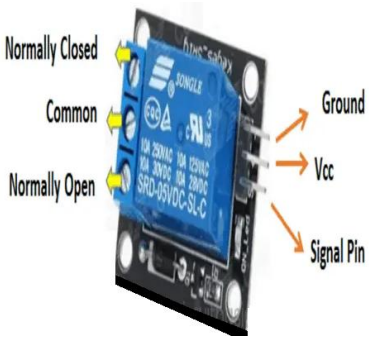

Figure 8. Typical relay

System Implementation

The block diagram in Figure 1 shows the components of the proposed intelligent vehicle gas and fire detection and suppression system. The central intelligence of the system is the Arduino microcontroller. The Arduino has three main functions: processes inputs, compares with thresholds and makes decisions, and triggers outputs.

All other parts of the system are connected to the Arduino microcontroller. The core components of the system include an Arduino microcontroller board, gas/smoke sensor, flame sensor, temperature sensor, LCD, actuation unit, solenoid valve, relay, water pump, and GMS. The sensors enable monitoring environmental conditions, and the detection of potential gas/smoke and fire hazards. The system utilizes solenoid valves and a spray nozzle system to automate fire suppression. Hence, the Arduino acts as the microcontroller, reading sensor inputs, processing logic, and sending commands to the actuators. It's the central hub that orchestrates the entire detection and suppression process.

Gas/smoke sensor (MQ2) has a variable resistor that changes its value based on the concentration of gas that it contacts. If the gas has a high concentration, then the resistance decreases. If the concentration of the gas is low, then the resistance increases. It is necessary to add a resistor which acts as a load. This resistor will adjust the sensor's sensitivity. The value of this resistor can range from 2K Ω to 47K Ω. As this value increases, the more sensitive the sensor becomes. When the sensor detects a certain concentration of gas/smoke (abnormal value), it triggers an LED alarm as a visual indicator. The LED alarm provides a quick and visible alert to users indicating a possible fire. This gives a chance to people to take necessary precautions in the presence of hazardous gases. Its analog output will be read by the Arduino analog pin A0 to determine the concentration of gas in the atmosphere. The MQ2 Gas Sensor circuit diagram is shown in Figure 9.

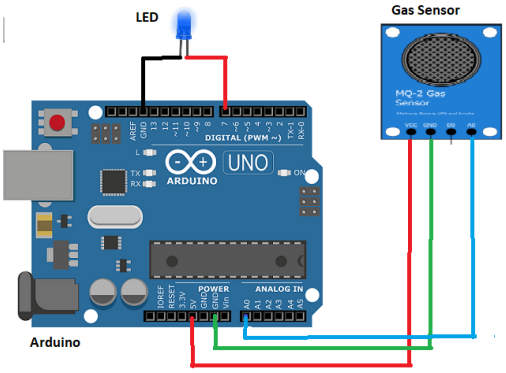

Figure 9. MQ2 gas sensor circuit diagram

IR Flame Sensor (REES52) is highly sensitive to infrared radiation, making it ideal for detecting flames. It uses infrared radiations emitted by flames to detect the presence of flames. The REES52 sensor converts this detection into a digital voltage signal, which is read by the Arduino at pin 7. When the signal exceeds a set threshold, the Arduino triggers a buzzer connected to pin 11 to provide an audible indication of the flame's presence. The audible buzzer serves as immediate indicator. The REES52 IR flame sensor circuit diagram is shown in Figure 10.

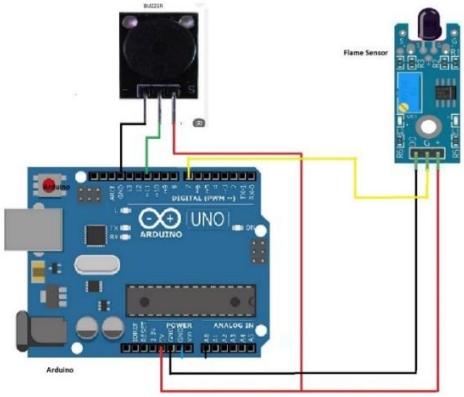

Figure 10. REES52 IR flame sensor circuit diagram

Temperature sensor (LM35) measures the temperature value and sends the data to the Arduino. This sensor will monitor the atmosphere temperature, triggering an alarm if it exceeds a predefined threshold. This is an indication of possible fire. The LM35 temperature sensor circuit diagram is shown in Figure 11.

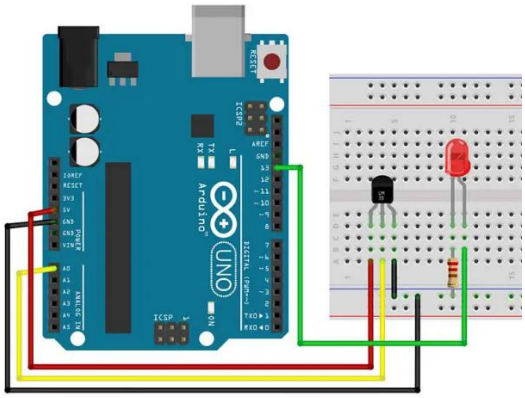

Figure 11. LM35 temperature sensor circuit diagram

The circuit diagram for the proposed intelligent vehicle safety systen is presented in Figure 12. Now, when fire, gas, or abnormal value for temperature is detected, the Arduino activates the 5V relay, allowing the 12V battery to power the solenoid valve and water pump initiate the fire suppression process. That is, the Arduino reads all sensors, displays data on the LCD, and sends its commands to the LEDs, buzzer, GSM network, relay, solenoid, pump, and the SG90 servo motor. The LEDs will light up and buzzer will release audible signal. The GMS will

send an SMS message alerts during emergencies “FIRE/GAS DTECTED” to the mobile that is stored in the programming code. The relay will turn ON and activate Normally Open (NO) to control the solenoid valve. The solenoid gets magnetized and pulls the armature towards itself leaving the valve open. The Arduino activates a pump. The Arduino will send out PWM signals to the SG90 servo motor to rotate the spray nozzle toward the fire. Then the embedded board in the servo receives the signals through the signal pin and controls the direction of the fire suppression spray nozzle.

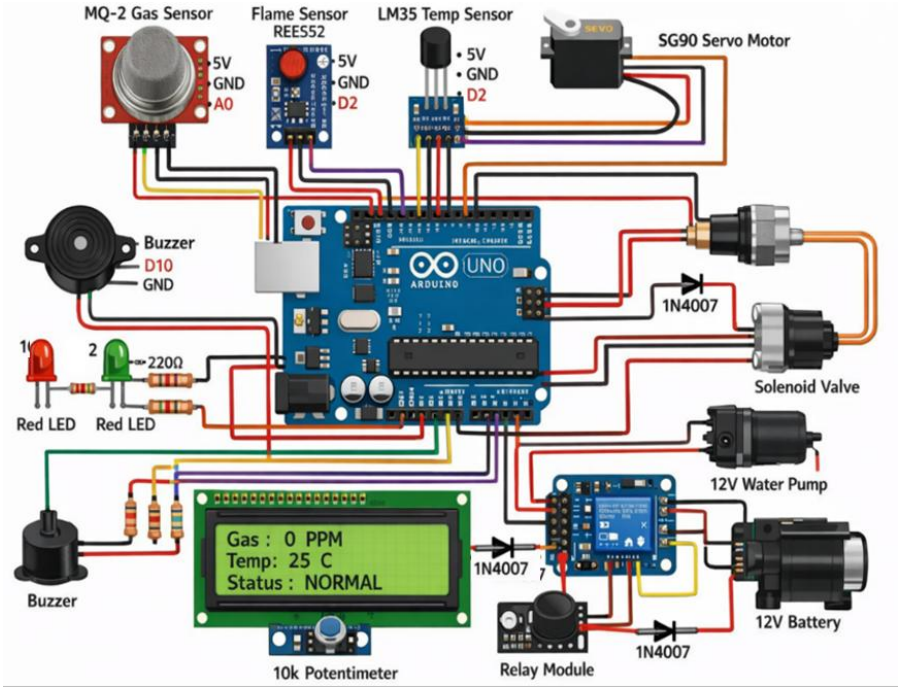

Figure 12. The circuit diagram for the proposed system

The diagram demonstrates the integration of sensing, processing, alerting, and actuation units, enabling early detection and effective suppression of fire and gas leakage in vehicular environments. The overall system operation is as follows. Sensors continuously monitor gas, flame, and temperature. Sensor data is sent to the Arduino controller. The Arduino evaluates the data against safety thresholds. Real-time data is displayed on the LCD. The code used to program the Arduino micocotroller was written using C++ programming language. If danger is detected:

- Buzzer is activated
- Red LED turns ON
- Relay switches ON (activates) the pump and solenoid
- Servo motor positions (rotates) the nozzle

Under normal conditions:

- Green LED remains ON
- Relay and pump remain OFF

Notice that sensors take 5V from Arduino, while pump and solenoid use external 12V battery.

Conclusion

The paper presented a comprehensive Arduino-based vehicle gas and fire detection and suppression system against one of the most dangerous vehicular hazards. This comprehensive vehicle safety system provides multi-layered protection against gas leaks, fires, and overheating and Automatic response without driver intervention. By integrating the MQ2 gas sensor, REES52 flame sensor, and LM35 temperature sensor for robust detection, and pairing them with an LCD, buzzer, LEDs for clear alerts, alongside an SG90 servo, relay, solenoid, and water pump for active suppression, the system offers a multi-layered approach to vehicle safety. The Arduino's

role as the central controller ensures seamless operation, making this design a practical and effective solution for enhancing vehicle safety against gas leaks and fires.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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