ADVANCED VEHICLE FIRE SAFETY AND MONITORING WITH RAPID EMERGENCY DISPATCH SOLUTIONS

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Final Report

B.Sc. (Hons) Degree in Information Technology specializing in Information Technology

Department of Information Technology

Sri Lanka Institute of Information Technology
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Dissertation submitted in partial fulfillment of the requirements for the Special Honours
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1. DECLARATION

We declare that this is our own work and this proposal does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgment is made in the text.

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The above candidates are carrying out research for the undergraduate Dissertation under my supervision.

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2. ABSTRACT

The increasing prevalence of vehicle fires necessitates innovative approaches to fire suppression that can respond rapidly and effectively. This research introduces a novel method for the automatic extinguishment of fires in vehicles. The proposed system integrates advanced fire detection and suppression mechanisms to enhance safety and minimize response time. The system is designed to automatically detect fire signals through specialized sensors, triggering an immediate response that includes the activation of an alarm and the deployment of fire extinguishers. A key feature of this system is the automatic release mechanism, which utilizes a solenoid valve directly connected to the fire extinguisher. Upon receiving a fire alert, the solenoid valve is activated, allowing CO2 to be released from the extinguisher to suppress the fire. The solenoid valve's precise and timely operation is crucial to ensuring the effectiveness of the fire suppression process. While a predictive model has been developed to identify potential fire risks and enhance the safety of drivers and passengers, the primary focus remains on the seamless integration of detection and suppression mechanisms, delivering a robust solution for vehicle fire emergencies. This approach not only promises to significantly improve vehicle safety and mitigate fire-related risks but also serves as a reliable backup system.

*Keywords: Vehicle fire suppression, automatic fire extinguishing, solenoid valve, fire detection system, CO2 release mechanism***.**

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7. LIST OF ABBREVIATION

IoT – Internet of Things

ML – Machine Learning

GPS – Global Positioning System

IDE - Integrated Development Environment

CO – Carbon Monoxide

OS – Operating System

AWS - Amazon Web Services

UI - User Interface

MQTT - Message Queuing Telemetry Transport

SPI - Serial Peripheral Interface

NC - Normally Closed (referenced in the context of solenoid valve specifications)

1.INTRODUCTION

1.1.Background and Literature Survey

Vehicle fires pose significant risks, including the loss of life and property, making the development of efficient fire detection and suppression systems essential. The increasing complexity of modern vehicles, coupled with the presence of flammable materials, has necessitated the adoption of advanced fire suppression technologies. Traditional fire suppression systems in vehicles often rely on manual activation, which can be delayed and less effective in critical situations. Consequently, there has been a growing interest in developing automated fire detection and suppression systems that can respond rapidly to fire incidents within vehicles.

When it comes to vehicle safety, the risk of an automotive fireplace stands out as a serious emergency that is frequently unexpected and underestimated by both drivers and passengers [1]. This lack of preparation combined with the rapid growth of the fire can cause panic, which increases the situation and causes extensive damage to the automobile and its occupants. It is also likely to be the primary cause of serious accidents, fatalities, and enormous financial losses. By introducing a cutting-edge solution that can identify potential fire hazards before they become serious emergencies, the proposed device seeks to close this gap in vehicle protection. This will revolutionize the way vehicle fires are managed and significantly improve passenger safety. [1]

Recent advancements in fire protection technologies, particularly the integration of Internet of Things (IoT) and automation, have provided promising solutions for addressing vehicle fire emergencies. For instance, the IoT-based fire protection system proposed by Kumar et al. introduces a framework for tracking and managing fire incidents across various settings, including industrial environments. This system utilizes a combination of sensors—such as flame, smoke, and gas sensors—coupled with communication modules like GSM and GPS to detect fire and promptly alert relevant authorities [2]. Similarly, Chandramohan et al. developed a multi-degree rotating fire extinguisher system designed for comprehensive coverage in building protection. This system is capable of rotating 360 degrees, ensuring that fire suppression agents are evenly distributed across all areas at risk of fire [3].

In the context of vehicle fire suppression, the work of Sowah et al. is noteworthy. They designed a fuzzy logic-based fire detection and control system specifically for automobiles. This system employs various sensors to monitor and respond to fire incidents, demonstrating the potential for integrating intelligent systems within vehicles to enhance fire safety [4]. Moreover, the comprehensive fire safety solutions proposed by Kumar et al. emphasize the importance of real-time data monitoring and automated response mechanisms in preventing the escalation of fire incidents [2].

Additionally, the device uses machine learning algorithms to analyze data collected from the vehicle's sensors, allowing it to predict the probability of a fire outbreak with accuracy. Predictive functionality plays a crucial role in early detection, enabling treatments that might prevent the fire from starting in the first place. Utilizing cloud technologies makes the system even more effective by enabling real-time data processing and storing, ensuring that emergency responders can easily access the information. Furthermore, by allowing the system to learn from past events, the cloud platform constantly improves the prediction accuracy and dependability of the system.

The suggested approach also takes into account the best path for emergency personnel to take in order to reach the automobile that is in danger, taking into account capacity constraints and current traffic conditions. This increases the likelihood of reducing the effects of the automobile fire by ensuring that help comes as soon as possible. The system uses cutting-edge IoT devices, GPS locators, and communication modules to achieve this level of sophistication [6]. These components work together to deliver precise and fast information to emergency services as well as automobile occupants.

Even if some of these devices are undoubtedly beneficial, innovation and implementation of modern technology address many difficult challenges. These include making the device affordable for widespread use, guaranteeing the dependability and accuracy of the sensors and algorithms used for fire detection, and resolving privacy and security concerns related to information gathering and communication. Apart from that, there's the project of integrating this gadget with the current infrastructures for emergency response and cars, which calls for cooperation between emergency services, software developers, and automakers [7].

This research aims to contribute to this evolving field by introducing a novel method for extinguishing vehicle fires. The proposed system will automatically detect fire signals using specialized sensors and deploy fire extinguishers without requiring manual intervention. A solenoid valve mechanism will be employed to control the release of CO2 from the fire extinguisher, ensuring a rapid and effective response to fire incidents. Additionally, a predictive model has been developed to enhance the safety of drivers and passengers by identifying potential fire risks in advance. While the predictive model is an integral part of the overall system, the primary focus of this research is on the seamless integration of detection and suppression mechanisms. This system also serves as a backup, providing an additional layer of protection in case the primary system fails or is insufficient.

The integration of IoT, sensor networks, and automation in fire suppression systems represents a significant advancement in vehicle fire safety. The proposed research will build on these advancements by developing a highly responsive and reliable fire suppression system specifically designed for vehicles, with the potential to significantly reduce the risks associated with vehicle fires.

1.2.Research Gap

While there has been significant progress in the development of fire detection and suppression systems, especially with the integration of IoT and automation technologies, several gaps remain that need to be addressed to enhance the efficacy and reliability of these systems in vehicle fire scenarios.

One critical gap is the focus of most existing systems on static environments, such as buildings and industrial facilities, rather than dynamic and confined spaces like vehicles. For example, the IoT-based fire protection systems designed by Kumar et al. [2] and the multi-degree rotating fire extinguisher system by Chandramohan et al. [3] are primarily tailored for large-scale environments where space constraints and mobility are not significant concerns. In contrast, vehicles present unique challenges due to their compact structure and the rapid spread of fire within confined spaces. The current literature does not sufficiently address the need for a system that can operate effectively within these constraints.

Another gap lies in the reliance on manual or semi-automatic systems in vehicles, which may not provide the rapid response required during a fire emergency. Although Sowah et al. [4] proposed an intelligent fire detection system using fuzzy logic for vehicles, this system still requires some level of manual intervention and lacks the fully automated suppression mechanism necessary for immediate fire mitigation. There is a clear need for a more comprehensive solution that not only detects fires but also automatically deploys suppression agents without human input.

Moreover, existing systems often focus on detecting fires after they have already started, without incorporating predictive models that could anticipate fire risks and provide preemptive alerts. While the proposed system does include a predictive model, this aspect has not been thoroughly explored in the current literature, particularly in the context of vehicles. The integration of such predictive capabilities with automated suppression systems presents a novel approach that could significantly enhance vehicle safety, yet it has not been fully developed or implemented in existing solutions.

There are systems that utilize solenoid valves for fire suppression in static environments, their application within the confined and rapidly changing conditions of a vehicle is underexplored. The research conducted by Kumar et al. [2] and Chandramohan et al. [3] provides a foundation for using solenoid valves, but these studies do not address the specific challenges of deploying such mechanisms in vehicles, where space, weight, and rapid response are critical factors.

While existing research has made strides in the development of fire detection and suppression systems, significant gaps remain in the context of vehicle fires. These gaps include the need for fully automated systems that operate effectively in confined spaces, the integration of predictive models for preemptive fire risk management, and the adaptation of suppression mechanisms like solenoid valves for use in vehicles. Addressing these gaps is essential for advancing the safety and reliability of fire suppression systems in vehicles.

1.3.Research Problem

The core research problem addressed by this study is the critical gap in the current state of fire suppression technology specifically designed for vehicles, where the need for a fully automated and highly responsive system is paramount. Existing fire suppression systems are predominantly engineered for static environments such as buildings or industrial facilities, where space is abundant, and the fire's spread can be more predictable. However, vehicles present a unique set of challenges, including confined spaces, limited airflow, and the rapid propagation of fires due to the presence of flammable materials like fuel, upholstery fabrics, and electrical components. These factors necessitate a tailored approach that traditional fire suppression systems fail to adequately address.

Current vehicle fire suppression solutions typically depend on manual intervention or semi-automated systems that may not respond quickly enough to contain a fire before it causes significant damage or endangers the lives of occupants. The lack of real-time automation in these systems presents a significant risk, particularly in situations where the driver or passengers are unable to activate the system due to incapacitation or lack of awareness.

Another crucial aspect missing in existing systems is the integration of predictive modeling. Most fire suppression systems react only after a fire has been detected, which, in the confined and volatile environment of a vehicle, may be too late to prevent serious consequences. Predictive models, which analyze data trends and anticipate fire risks before they manifest, offer a proactive approach to fire safety that is currently underutilized in vehicle applications.

This research seeks to bridge these significant gaps by developing an innovative fire suppression system specifically engineered for vehicles. The proposed system will combine advanced fire detection capabilities with a fully automated suppression mechanism that leverages a solenoid valve for rapid and precise deployment of extinguishing agents. This system is designed to operate autonomously, ensuring a swift response that does not rely on human intervention. Additionally, by incorporating predictive modeling, the system aims to anticipate fire hazards and take preemptive actions to mitigate them, thereby significantly enhancing the overall safety and reliability of vehicles in fire emergencies.

1.4. Objectives

1.4.1. Main Objective

The primary objective of this research is to design and implement a sophisticated, fully automated fire suppression system specifically tailored for vehicles, with the capability to detect and respond to fire incidents in real time. The system aims to integrate multiple advanced technologies, including a network of sensors that continuously monitor the vehicle's environment for signs of fire, such as rapid temperature increases, the presence of smoke, or the detection of flames. Upon identifying potential fire risks, the system will immediately trigger an automated response mechanism, activating fire suppression measures like the release of fire extinguishing agents through a solenoid valve. The system is designed to operate autonomously, without requiring manual intervention, ensuring that it can respond to fire incidents even if the driver or passengers are incapacitated or unaware of the danger. Additionally, the system will be equipped with communication capabilities to alert the vehicle occupants through voice alerts and notify emergency services or a designated mobile application, thereby facilitating a coordinated response to the fire emergency.

The ultimate goal is to develop a robust and reliable fire suppression system that significantly improves vehicle safety, minimizes fire-related risks, and enhances the overall security of both passengers and vehicles through the use of cutting-edge technologies.

1.4.2. Specific Objectives

Design and Integration of Fire Detection Mechanisms

This sub-objective focuses on developing a reliable and responsive IoT-based fire detection system tailored for the unique and confined environment within a vehicle. To achieve this, the system incorporates the MAX6675 module paired with a K-type thermocouple sensor to accurately measure temperature changes, which can be an early indicator of fire. The MAX6675 is known for its ability to provide precise temperature readings over a wide range, making it ideal for detecting the rapid temperature increases associated with vehicle fires.

In addition to temperature monitoring, the system utilizes the MQ2 sensor, a versatile gas sensor capable of detecting smoke, which often precedes or accompanies a fire. The combination of these two sensors allows the system to monitor both temperature and air quality within the vehicle, providing a comprehensive fire detection solution.

The data from these sensors is collected and processed by an Arduino Mega, chosen for its multiple I/O pins and robust processing power, which is necessary to manage the inputs from multiple sensors simultaneously. The Arduino Mega not only handles the data processing but also feeds the sensor data to an MQTT server. This server facilitates real-time communication between the fire detection system and other components, such as the mobile application and the automatic fire extinguishing mechanism.

Development of a Solenoid Valve-Based Suppression Mechanism

This sub-objective involves the development of an automatic fire suppression system using a solenoid valve, specifically designed to deploy fire extinguishers within a vehicle in response to detected fire hazards. The solenoid valve is integral to this system as it serves as the actuator that triggers the release of the fire extinguishing agent. In this case, the solenoid valve is attached to a dry powder fire extinguisher, which is chosen for its effectiveness in combating various types of fires commonly encountered in vehicles.

When the system's sensors (MAX6675 module and MQ2 sensor) identify a potential fire, the system generates a fire alert that triggers multiple responses. Firstly, an alarm buzzes within the vehicle, providing an audible warning to the occupants. Simultaneously, the solenoid valve is activated, causing the fire extinguisher to deploy its contents rapidly to suppress the fire before it can spread.

In addition to the physical deployment of the fire extinguishing agent, the system is designed to interact with a mobile application through an IoT connection. As soon as the fire alert is generated, the vehicle owner receives an immediate notification via the mobile app. This alert not only informs the owner of the fire incident but also provides real-time updates on the situation within the vehicle. Furthermore, the system is configured to notify the local fire department, providing them with the vehicle's exact location. This feature ensures that emergency responders are promptly informed and can take necessary actions if the situation escalates.

System Integration and Testing in Vehicle Environments

This sub-objective involves the seamless integration of all system components, the solenoid valve suppression mechanism, and the predictive fire risk model within the vehicle's existing systems. The integration process must ensure that all components work simultaneously to provide a comprehensive fire suppression solution. This task also includes rigorous testing under both simulated and real world conditions like wet conditions, dry conditions, cold conditions, heat conditions etc, to validate the system's performance, reliability, and effectiveness. The testing phase is crucial to identify any potential issues and ensure that the system can operate under various scenarios, including different types of fires, vehicle speeds, and environmental conditions.

Design of the Alert System:

Physical deployment of the fire extinguishing agent, the system is designed to interact with a mobile application through an IoT connection. As soon as the fire alert is generated, the vehicle owner receives an immediate notification via the mobile app. This alert not only informs the owner of the fire incident but also provides real-time updates on the situation within the vehicle. Furthermore, the system is configured to notify the local fire department, providing them with the vehicle's exact location. This feature ensures that emergency responders are promptly informed and can take necessary actions if the situation escalates.

The continuous IoT connectivity between the vehicle and the mobile application allows the owner to monitor the vehicle's status in real-time, even when away from the vehicle. This real-time insight is crucial for enabling rapid decision-making in the event of a fire emergency, ensuring that the fire suppression system operates effectively and that help can be dispatched without delay.

By integrating the solenoid valve with the IoT-based alert system and ensuring seamless communication with emergency services and the vehicle owner, this sub-objective aims to create a reliable, responsive, and automated fire suppression mechanism that enhances the overall safety of the vehicle.

Evaluation of System as a Backup Mechanism:

The final sub-objective is to evaluate the system's capability to function as a reliable backup to existing fire suppression systems in vehicles. This involves testing the system's independence and its ability to provide an additional layer of protection. The evaluation process will include scenarios where the system must operate autonomously, ensuring that it can still detect and respond to fire incidents even if the primary system is compromised. This redundancy is critical to enhancing overall vehicle safety and ensuring that the fire suppression system can be relied upon in emergencies.

2. METHODOLOGY

2.1. System Architecture

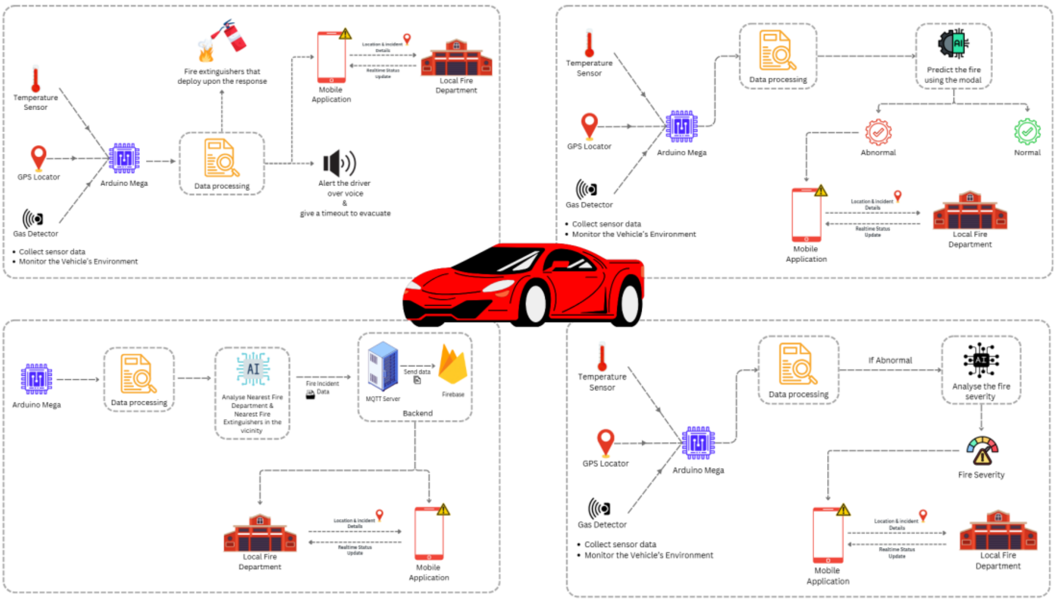


Figure 1System Architecture Diagram

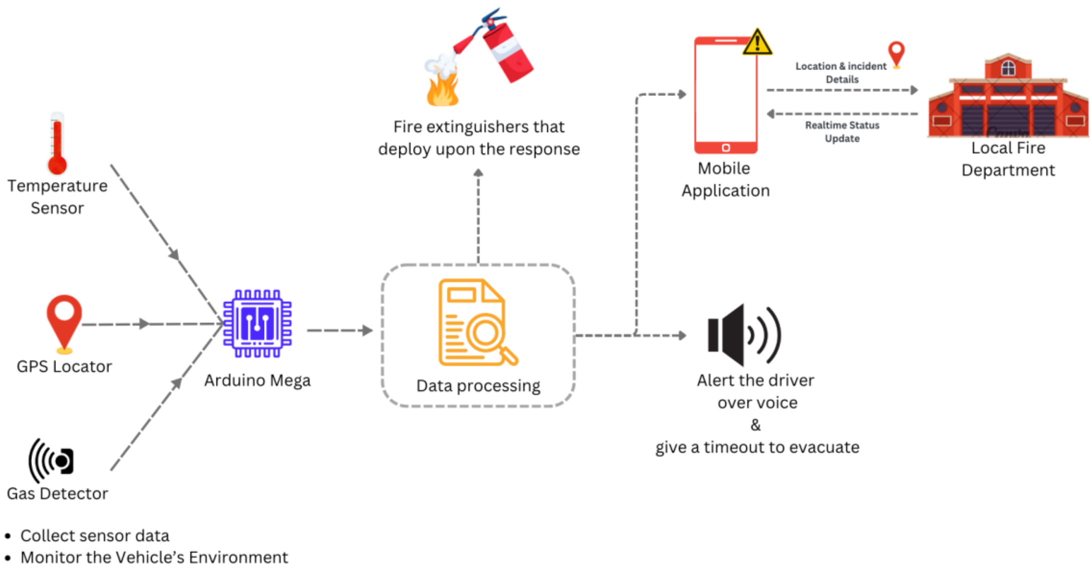


Figure 2 Component Architecture Diagram

The system architecture of the proposed vehicle fire detection and suppression system is designed to operate as a robust and integrated safety mechanism that ensures the protection of both vehicle occupants and the vehicle itself. At the heart of this architecture are three critical sensors: a temperature sensor (MAX6675 Module with K Type Thermocouple), and a gas detector (MQ2 sensor) and a GPS locator (Ublox NEO-6M GPS Module) . These sensors are strategically placed within the vehicle to continuously monitor environmental conditions that could indicate the presence of a fire as well as the location of the vehicle. The data collected by these sensors is transmitted to an “Arduino MEGA” microcontroller board, which functions as the central processing unit of the system. The “Arduino MEGA” is equipped with the capability to handle real-time data processing, making it ideal for analyzing the sensor inputs to detect any fire-related anomalies.

Upon detection of a potential fire, the data processing unit within the “Arduino MEGA” initiates a series of automated responses. Firstly, it triggers the deployment of fire extinguishers, which are strategically positioned to cover all areas of the vehicle, ensuring rapid suppression of the fire. Simultaneously, the system sends an alert to a connected mobile application, notifying the driver and potentially other stakeholders of the emergency. This alert mechanism is crucial for providing real-time information and enabling quick decision-making in response to the fire. Additionally, the system activates a alert within the vehicle, which serves two purposes, it immediately informs the driver of the danger and provides a timed countdown to allow for safe evacuation before the fire suppression system is fully activated. This multi-layered approach ensures not only the rapid detection and suppression of fires but also the safety of the vehicle's occupants, making it a comprehensive solution for fire emergencies in vehicles.

2.1.1. Software methodology

Requirement Gathering: Clearly define the goals of the safety system, including fire detection, toxic gas leak identification, and emergency alerting capabilities. And clearly identify the requirements of the mobile application and the proposed IoT system. Engage with potential users, emergency response teams, and automotive experts to gather insights and expectations.

Market Research: Analyze existing solutions and identify gaps between the products that can focus on the unique value of the proposed system.

Use Case Scenarios: Develop use case scenarios and personas to guide the design process and ensure the system meets varied user needs and fine-tune the requirements better.

System Architecture: Design the overall system architecture, specifying how sensors, data processing units, and communication systems interact. And design the component-wise System Architectures to identify the components properly and clearly. Then it will be easy to identify which component connects which.

Technology Selection: Choose appropriate technologies, including sensors (smoke, gas, thermal sensor, fire sensor), processing units (ESP 32 module), and software tools (Arduino Ide, Firebase or AWS IoT, React Native or Flutter,). These technologies may vary as the project goes on [8].

Sprint planning: create task list and break it down into sprints. One sprint means 2 weeks. Allocate the tasks according to the weight of the task into sprints. And always monitor the sprint plan and the actual work done during the sprint. And plan the remaining work to complete in the upcoming sprint and adjust the sprint plan accordingly.

Code reviews: Do code reviews with the team members at the end of the sprint. And make sure a user-friendly codebase will be maintained throughout the project.

Prototype Development: Hardware Assembly begins with assembling the hardware components like sensors, cameras, and the ESP 32 module.

Software Development: Write the initial code for data gathering, processing, and emergency alerting, using MicroPython within the Anaconda and Jupyter Notebook IDE. The target is to program the Hardware components to work properly. A mobile application will be developed in order to provide the best experience to the users.

Integration: Integrate hardware and software components to create a functional prototype for initial testing.

System Testing: Test individual components (sensors, software modules) for functionality and reliability. Test the integrated system to ensure seamless operation and data flow between components. Conduct testing with potential users to gather feedback on system usability, effectiveness, and any adjustments needed. Repeat testing cycles to ensure all refinements are effectively implemented and new issues are addressed.

Deployment and Commercialization: Implement the system in a limited, controlled environment to validate its functionality in real-world scenarios. Prepare for larger-scale production, ensuring the quality and reliability of hardware components, and officially launch the product to the market.

This tour ensures a thorough approach from concept to deployment and beyond by embracing the automotive safety system development lifecycle.

2.1.2. Hardware Technologies

Microcontroller and Embedded Systems:

Arduino MEGA Microcontroller: Central processing unit for handling sensor data, executing control logic, and managing communication between components.

Microcontroller: ESP32 Microcontroller with Wi-Fi and Bluetooth connectivity, supporting real-time data processing as well

Sensors and Hardware Components:

- Flame Detection Sensor: Detects the presence of flames, triggering the fire suppression system. Infrared-based flame sensors that can detect specific wavelengths emitted by fire.
- Temperature Sensor (MAX6675 **)**: Monitors ambient temperature to detect potential fire conditions. Digital temperature sensors providing accurate readings.

- Gas Detector (MQ-2): Detects smoke or hazardous gases that could indicate a fire. Semiconductor sensors that detect a range of gases and send analog signals to the Arduino MEGA microcontroller.

Communication and Networking:

- Wi-Fi Modules (ESP32): Enables wireless communication for remote monitoring and control. Built-in Wi-Fi capability within ESP32 to connect to cloud services and mobile apps.
- Bluetooth (integrated in ESP32): Local communication with mobile devices for alerts and controls. Bluetooth Low Energy (BLE) for power-efficient communication.

Mobile Application Development:

- React Native: Cross-platform mobile application development for Android and iOS. Allows the creation of responsive, native-like mobile apps that interface with the fire detection system for real-time alerts.

2.2. Commercialization of the Product

8. **Patent Protection:** Make sure the product has sufficient protection against theft before releasing it onto the market. Getting patents for this novel idea may provide a competitive advantage and is essential to attract partners and investors.
9. **Pilot Programs**: For the deployment of pilot programs into action, work with fleet managers or manufacturers. This enables to get valuable feedback, show the efficiency and dependability of the system in real-world settings, and make any adjustments to the product prior to a launch.
10. **Strategic Partnerships:** Establish partnerships with automakers, suppliers of emergency response equipment, or insurers. Collaboration with such partners may bring beneficial outcomes including access to established customers, and chances for co-branding, advertising, and distribution.
11. **Direct Sales to Customers:** To sell directly to customers, make use of online platforms and e-commerce platforms. This approach may work especially well if

the system is made for aftermarket installation. Sales may be increased by educating potential consumers**.**

12. **Government and Regulatory Approvals:** Seek certifications and approvals from pertinent regulatory and government agencies. In addition to giving this product more legitimacy, this might lead to customers for required installations in specific areas, which would greatly increase the number of potential consumers we could reach.
13. **Trade exhibitions and Expos**: To introduce this product to a larger audience, take part in safety conferences, technology expos, and car trade exhibits.

2.3. Testing and Implementation

Flarepath is an integrated vehicle fire detection and response system, encompassing hardware integration, software development, IoT connectivity, mobile application functionality, and comprehensive system testing. The project involved assembling and programming key components such as the MAX6675 with a K-type thermocouple sensor, MQ2 smoke sensor, solenoid valve, Ublox NEO-6M GPS Module, and Arduino MEGA microcontroller. These components were interconnected to facilitate data processing and fire extinguishing mechanisms. Software was meticulously crafted for data handling and communication with an MQTT server, which in turn, linked the hardware to a mobile application designed to alert the vehicle owner and fire department instantly in case of fire. The system was installed in a vehicle and subjected to rigorous testing under various simulated conditions to ensure reliability, accuracy, and speed of response in real-world scenarios.

2.3.1. Implementation

Hardware Integration:

The first step involves the integration of all hardware components, including the MAX6675 module with the K-type thermocouple sensor, MQ2 smoke sensor, solenoid valve, Ublox NEO-6M GPS Module and Arduino MEGA microcontroller. Each component is connected according to the designed circuit diagrams, with the sensors feeding data into the Arduino Mega, which processes the information and triggers the solenoid valve in the event of a fire.

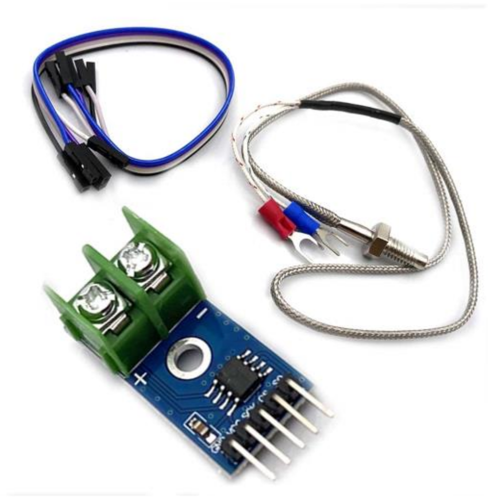


Figure 3 MAX6675 Module with K Type Thermocouple

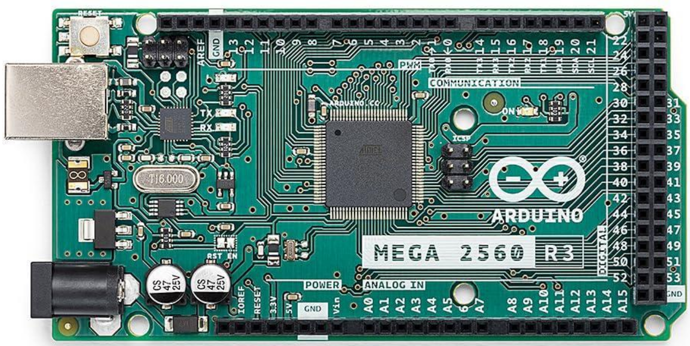


Figure 4 Arduino Compatible Mega 2560

Figure 5 NEO-6M GPS Module with Active Antenna

Figure 6 MQ-2 LPG CH4 CO H2 Alcohol Smoke Butane Methane Propane Gas Detection Module

Figure 7 5VDC 1 Way 1 Channel Relay Module

Figure 8 Electric Solenoid Valve 0.25-inch 12VDC NC Metal Water S179

Figure 9 Dry powder fire extinguishers

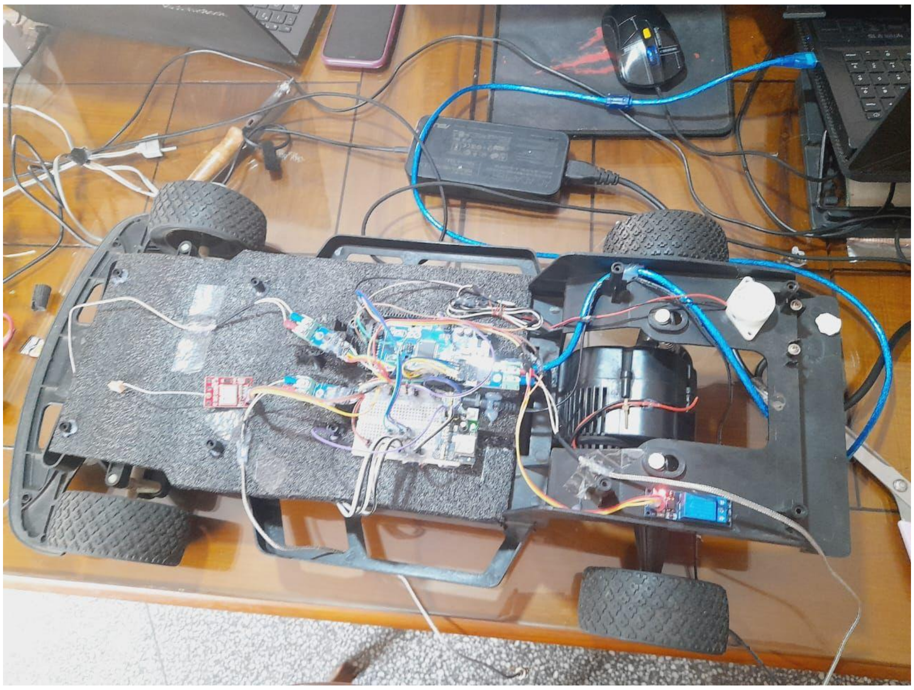


Figure 10 Integration of all hardware components

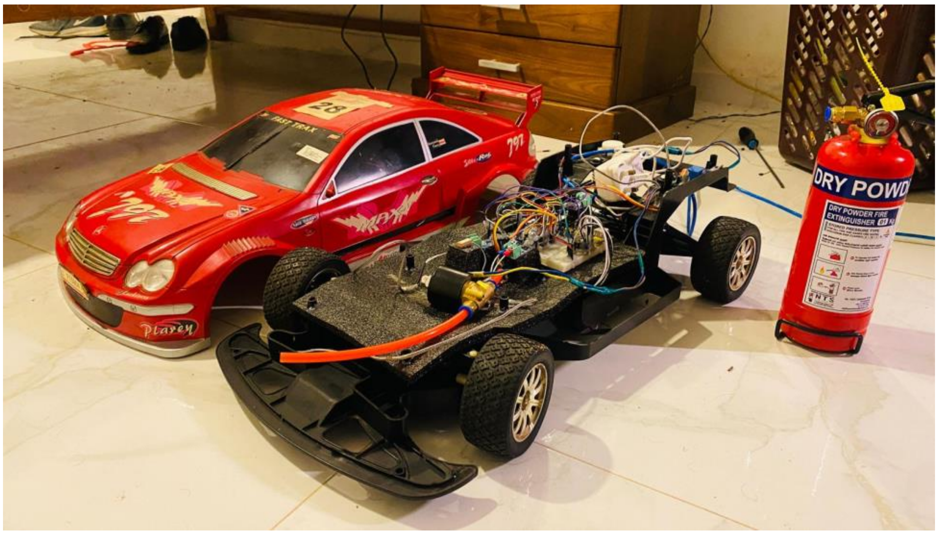
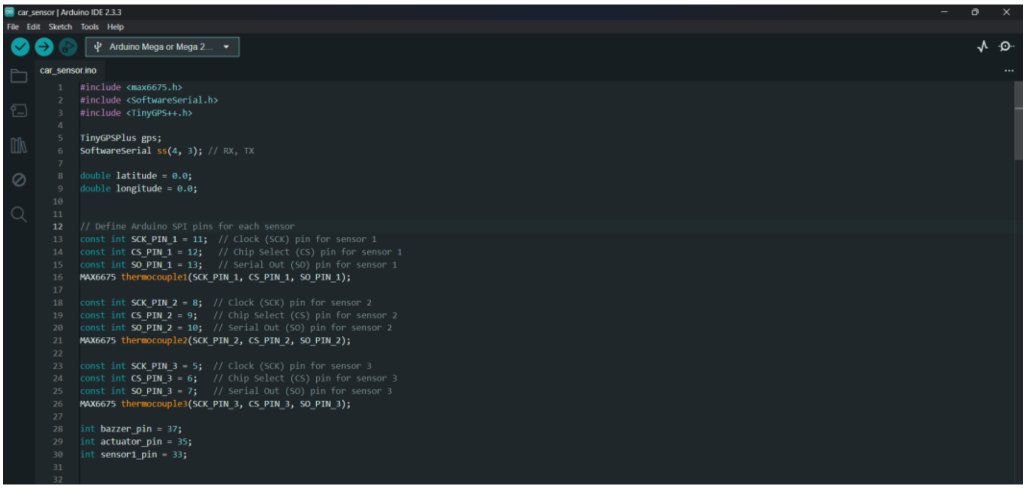


Figure 11 Integration of all hardware components

Software Development:

The software component involves writing code for the Arduino Mega to handle data acquisition from the sensors, processing the data, and determining the appropriate response. The code also includes communication protocols to send alerts to the MQTT server, mobile application, and fire department.



```
#include <max6675.h>
#include <SoftwareSerial.h>
#include <TinyGPS++.h>

TinyGPSPlus gps;
SoftwareSerial ss(4, 3); // RX, TX

double latitude = 0.0;
double longitude = 0.0;


// Define Arduino SPI pins for each sensor
const int SCK_PIN_1 = 11;  // Clock (SCK) pin for sensor 1
const int CS_PIN_1 = 12;   // Chip Select (CS) pin for sensor 1
const int SO_PIN_1 = 13;   // Serial Out (SO) pin for sensor 1
MAX6675 thermocouple1(SCK_PIN_1, CS_PIN_1, SO_PIN_1);

const int SCK_PIN_2 = 8;  // Clock (SCK) pin for sensor 2
const int CS_PIN_2 = 9;   // Chip Select (CS) pin for sensor 2
const int SO_PIN_2 = 10;  // Serial Out (SO) pin for sensor 2
MAX6675 thermocouple2(SCK_PIN_2, CS_PIN_2, SO_PIN_2);

const int SCK_PIN_3 = 5;  // Clock (SCK) pin for sensor 3
const int CS_PIN_3 = 6;   // Chip Select (CS) pin for sensor 3
const int SO_PIN_3 = 7;   // Serial Out (SO) pin for sensor 3
MAX6675 thermocouple3(SCK_PIN_3, CS_PIN_3, SO_PIN_3);

int bazzer_pin = 37;
int actuator_pin = 35;
int sensor1_pin = 33;
```

Figure 12 Import necessary libraries and Define Arduino SPI pins for each sensors

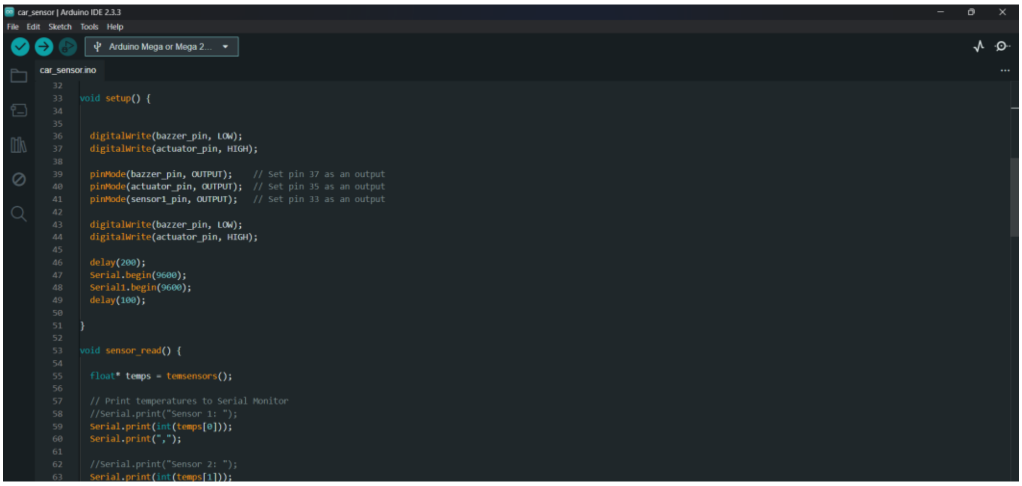


Figure 13 Setup pins with necessary input output signals

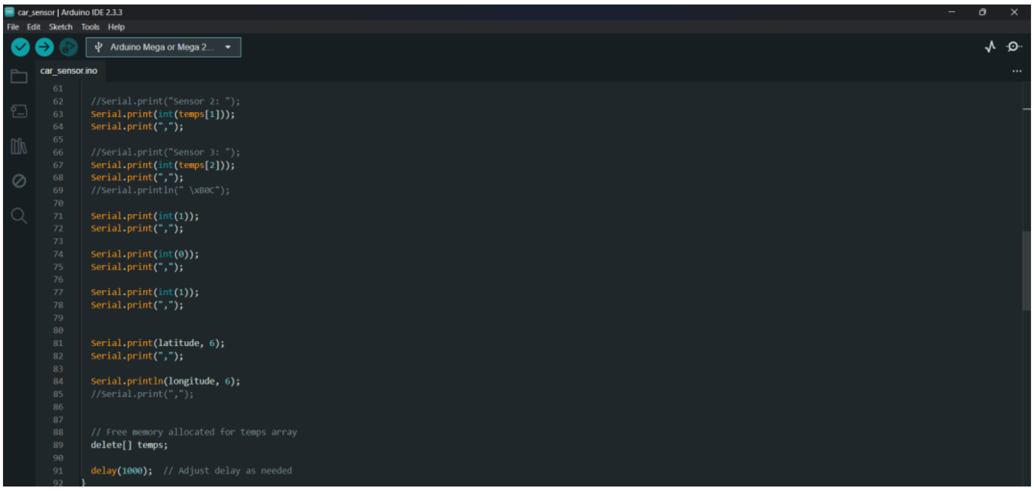


Figure 14 Print output results meaningfully

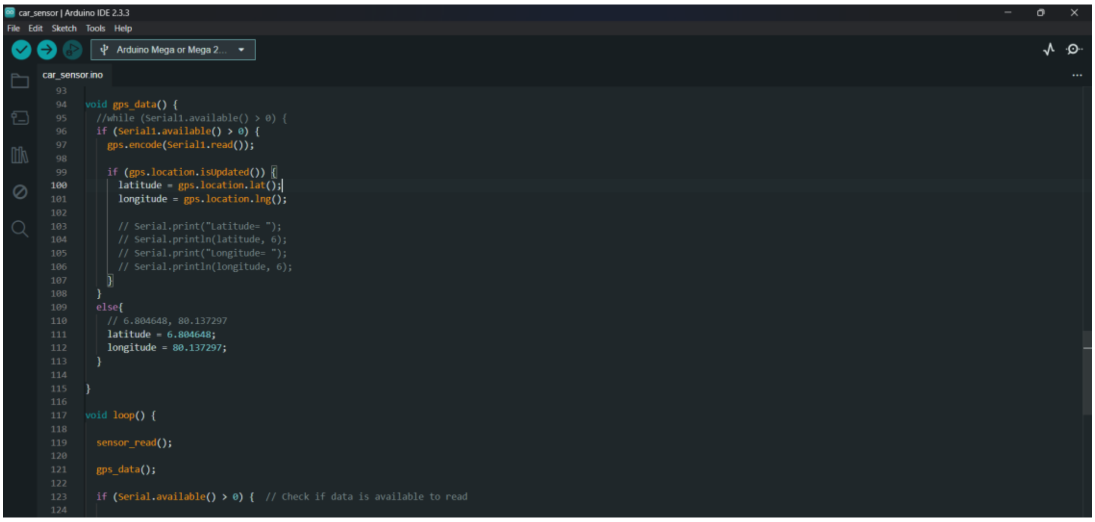


Figure 15 Setup GPS sensor (neo 6m module)

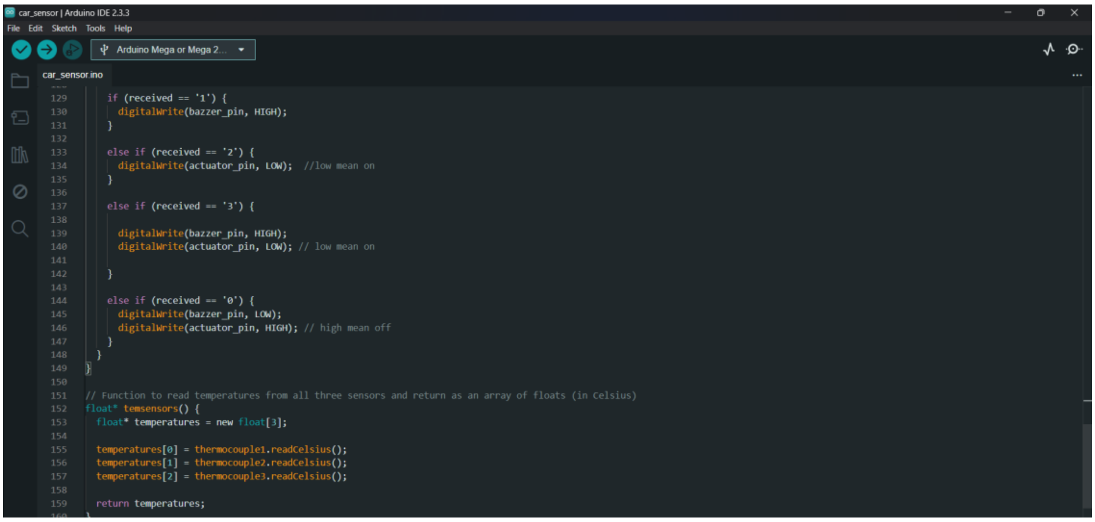


Figure 16 Check if data is available to read inside the while loop

IoT Integration:

The system is connected to an MQTT server, facilitating real-time data transmission between the vehicle's hardware and the mobile application. This integration allows for instant alerts and continuous monitoring, ensuring that the vehicle owner is always informed of the system's status.

```python
import serial # UART-based communication with the Arduino.
import time # for delays.
import threading # to allow parallel execution of sensor data


w_sensors = [0,0,0,0,0,0,0,0,0,0] #  Holds the current sensor readings (temperature and GPS coordinates).

act_command = [0,0]

# Indicates if a reset command is requested.
act_command_reset = False


# Returns the current sensor data stored in w_sensors.
def get_sensor_data():
    global w_sensors , act_command
    return w_sensors


# Updates act_command to send a new actuator command.
def send_actuators_data(to_act_command):

    global act_command
    act_command = to_act_command



# to request an actuator reset.
def send_actuators_reset(to_act_command_reset):

    global act_command_reset
    act_command_reset = to_act_command_reset



#  handle communication with the Arduino
def run_sensor_task(serial_port='COM3', baud_rate=9600):  ########  <------ Set comport
```

Figure 17 Import Libraries

```python

#  handle communication with the Arduino
def run_sensor_task(serial_port='COM3', baud_rate=9600):  ########  <------ Set comport

# Uses UART ptotocol to serial communicate
    ser = serial.Serial(serial_port, baud_rate, timeout=1)

# Sends a command to the Arduino
    def send_command(command):
        ser.write(command.encode())


# Reads a line from the serial port, decodes it, and splits it into sensor values
    def read_sensor_values():

        line = ser.readline().decode('utf-8').strip()

        # Split the line by comma
        data = line.split(',')

        # Print the data

        if len(data) == 8:
            # print(data)

            temsensor1 = int(data[0])
            temsensor2 = int(data[1])
            temsensor3 = int(data[2])

            gassensor1 = int(data[3])
            gassensor1 = int(data[4])
            gassensor1 = int(data[5])

            gps_long = data[6]
            gps_lat = data[7]

            return data
```

Figure 18 Reads a line from the serial port, decodes it, and splits it into sensor values arduino_communication_2.py × | main_car.py | car_temp_abnomility.py 1

Car > arduino_communication_2.py > send_actuators_data

```python
def run_sensor_task(serial_port='COM3', baud_rate=9600):   ########  <------ Set comport

# continuous loop for reading and processing sensor data.
    def sensor_task():
        try:

            global w_sensors , act_command , act_command_reset

            warmup = 0

            while True:

                if warmup == 0:
                    while True:
                        sensor_values = read_sensor_values()
                        if len(sensor_values) == 8:
                            warmup = 1
                            # print("System rady to use :)  ..........")
                            break
                        # print("System Not rady or fault")
                        time.sleep(1)
                else:

                    sensor_values = read_sensor_values()



                if sensor_values is not None:
                    # print("Sensor 1: {sensor_values[0]}, Sensor 2: {sensor_values[1]}, Sensor 3: {sensor_values[2]},
                    #       Sensor 4: {sensor_values[3]}, Sensor 5: {sensor_values[4]}, Sensor 6: {sensor_values[5]}" #gas
                    #       f", Sensor 6: {sensor_values[6]}, Sensor 6: {sensor_values[7]}")   # GPS --> All comeing as str

                    veryfi = 1


                    w_sensors = [ int (sensor_values[0]),int (sensor_values[1]),int (sensor_values[2]),
```

Figure 19 continuous loop for reading and processing sensor data.

arduino_communication_2.py × | main_car.py | car_temp_abnomility.py 1

Car > arduino_communication_2.py > send_actuators_data

```python
def run_sensor_task(serial_port='COM3', baud_rate=9600):   ########  <------ Set comport
    def sensor_task():

# Sends actuator commands based on the value of act_command.
                if act_command != [0,0]:

                    print('send command - ',act_command)

                    if act_command == [0,1]:
                        send_command('1')


                    if act_command == [1,0]:
                        send_command('2')

                    if act_command == [1,1]:
                        send_command('3')

                    if act_command == [0,1]:
                        send_command('4')

                    time.sleep(0.1)
                    act_command = [0, 0]


# Sends a reset command ('0') to the Arduino
                if act_command_reset == True:

                    send_command('0')
                    time.sleep(0.1)
                    act_command_reset = False


                time.sleep(0.9)

        except KeyboardInterrupt:
```

Figure 20 Sends actuator commands based on the value of act_command.

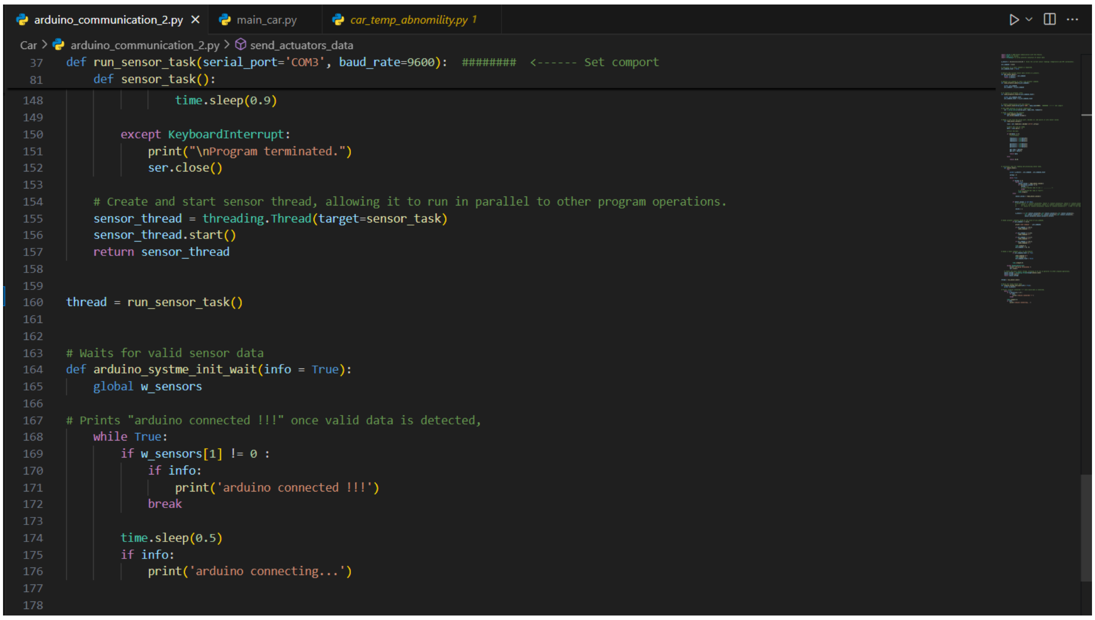


Figure 21 Sends a reset command

Mobile Application Setup:

The mobile application is developed using a cross-platform framework like React Native, enabling it to receive real-time alerts from the MQTT server, display the vehicle's status, and notify the vehicle owner and fire department in the event of a fire.

Deployment:

The system is installed in a vehicle, with sensors strategically placed to maximize fire detection coverage. The solenoid valve and fire extinguisher are mounted securely, ensuring they can deploy effectively when triggered.

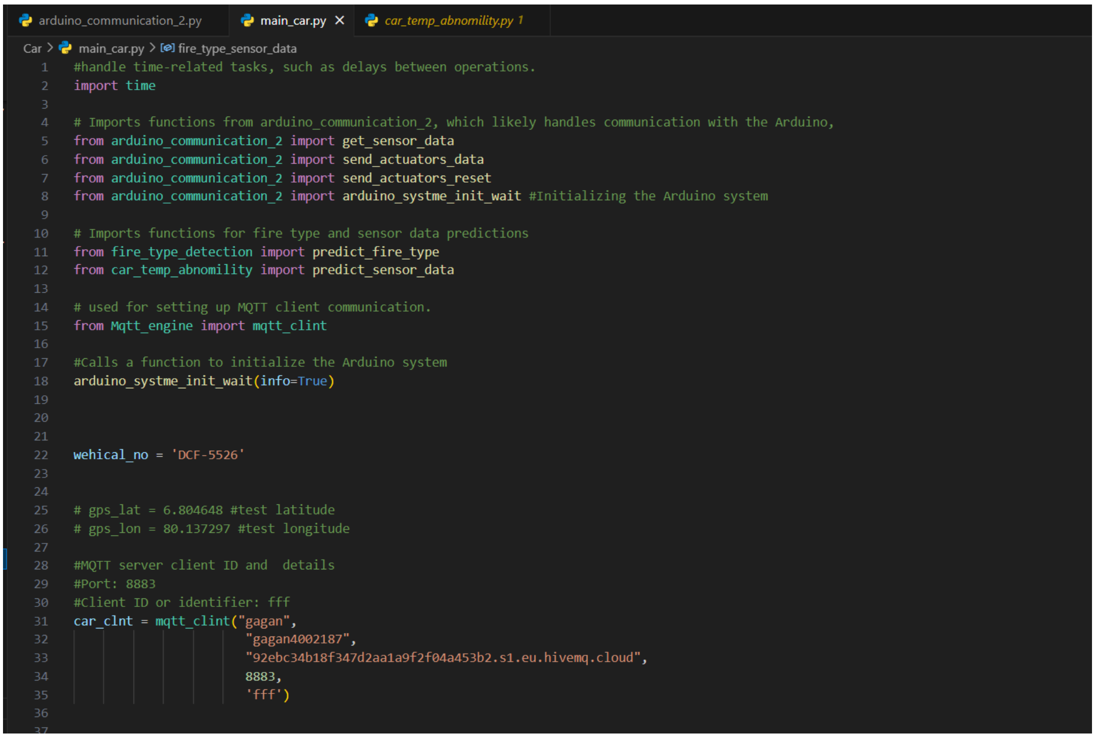


Figure 22 Imports functions from arduino_communication_2, which likely handles communication with the Arduino,

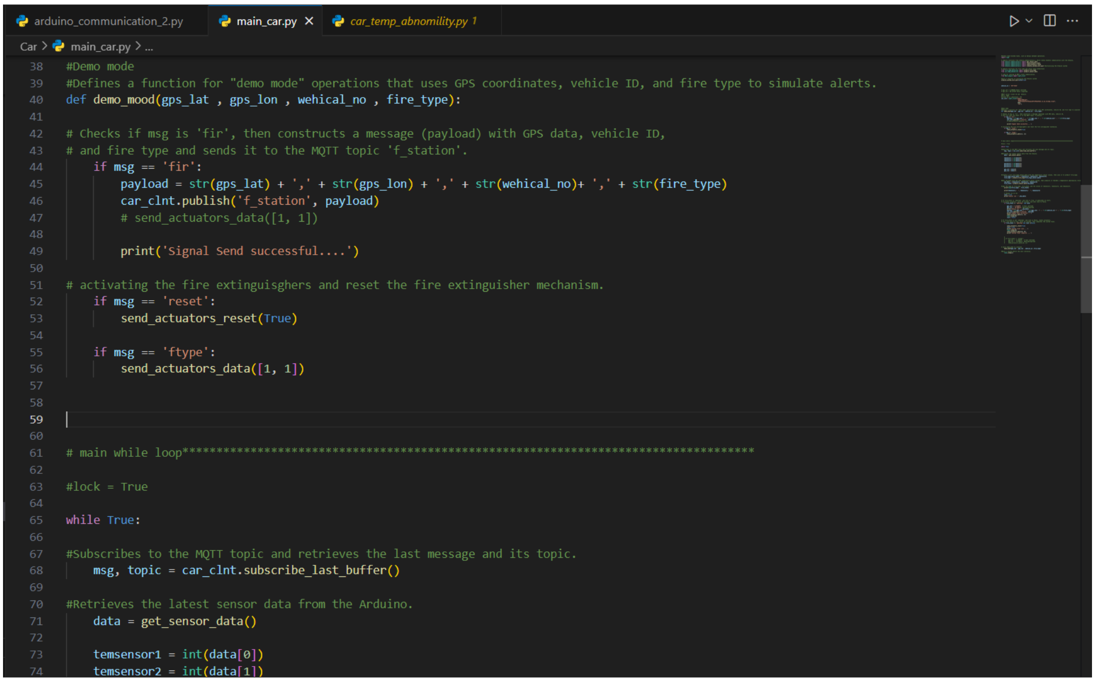


Figure 23 Defines a function for "demo mode" operations that uses GPS coordinates, vehicle ID, and fire type to simulate alerts.

```python
#Subscribes to the MQTT topic and retrieves the last message and its topic.
    msg, topic = car_clnt.subscribe_last_buffer()

#Retrieves the latest sensor data from the Arduino.
    data = get_sensor_data()

    temsensor1 = int(data[0])
    temsensor2 = int(data[1])
    temsensor3 = int(data[2])

    gassensor1 = int(data[3])
    gassensor2 = int(data[4])
    gassensor3 = int(data[5])

    gps_lat = data[6]
    gps_lon = data[7]


#Creates a list fire_type_sensor_data with the temperature sensor values, then uses it to predict fire_type.
    fire_type_sensor_data = [temsensor1, temsensor2, temsensor3]
    fire_type = predict_fire_type(fire_type_sensor_data)

#Sets new_data with the same temperature sensor values, then predicts if there's a temperature abnormality (fire_state).
    new_data = [temsensor1, temsensor2, temsensor3]
    fire_state = predict_sensor_data(new_data)

#Logs the type of fire_type, fire_state, and the values of temsensor1, temsensor2, and temsensor3.
    print(type(fire_type) , fire_state)

    print(temsensor1,"  ", temsensor2,"  ", temsensor3)

    # fbsend (t1 t2 t3)
    lock = True
    print("Sensor val - ",new_data)

```

Figure 24 Retrieves the latest sensor data from the Arduino.

```python


# If fire_state is 'abnormal' and lock is True, it publishes an alert,
# activates actuators, waits 30 seconds, and sets lock to False.
    if fire_state == 'abnormal' and lock:

        gps_lat = '6.926878'  # Test latitude
        gps_lon = '79.850117' # Test longitude
        print("Sensor val - ",new_data)
        payload = str(gps_lat) + ',' + str(gps_lon)  + ',' + str(wehical_no) + ',' + str(fire_type)
        car_clnt.publish('f_station', payload)
        print('Signal Send successful....')
        send_actuators_data([1, 1])
        time.sleep(30)
        lock = False

# If fire_state is not 'abnormal' and lock is False, resets actuators,
# sets lock back to True, waits 10 seconds, then completes the system reset.
    if fire_state != 'abnormal'and lock ==False:

        send_actuators_reset(True)
        lock = True
        print('System reset init....')
        time.sleep(10)
        send_actuators_data([0, 0])
        print('System reset complete ....')


    #
    # if fire_state != 'normal':
    #     gps_lat = '6.926878'  # Test latitude
    #     gps_lon = '79.850117' # Test longitude
    #     send_actuators_data([0, 1])


# Calls demo_mood to simulate
    demo_mood(gps_lat , gps_lon , wehical_no ,fire_type)
```

Figure 25 Based on the fire_state system publishes an alert to trigger the Automatic fire extinguisher mechanism

2.3.2. Testing

Each component, such as the sensors, solenoid valve, and Arduino code, is tested individually to ensure it functions correctly. For example, the thermocouple sensor is tested to confirm accurate temperature readings, while the MQ2 sensor is tested for its ability to detect smoke. After individual components are validated, they are tested together to ensure seamless integration. This includes testing the communication between the sensors, Arduino Mega, MQTT server, and mobile application. The system is checked for proper data flow, ensuring that a detected fire triggers all necessary responses, including alarm activation, solenoid valve deployment, and alert notifications. The system is tested in controlled environments that simulate real-world fire scenarios within a vehicle. These tests include controlled temperature increases and the introduction of smoke to ensure the sensors detect the fire accurately and that the system responds appropriately by deploying the fire extinguisher and sending alerts. The system's performance is tested under different conditions, including varying temperatures, vibrations, and speeds to ensure it remains reliable under all circumstances. The response time is measured to ensure that the system reacts swiftly enough to prevent fire escalation.

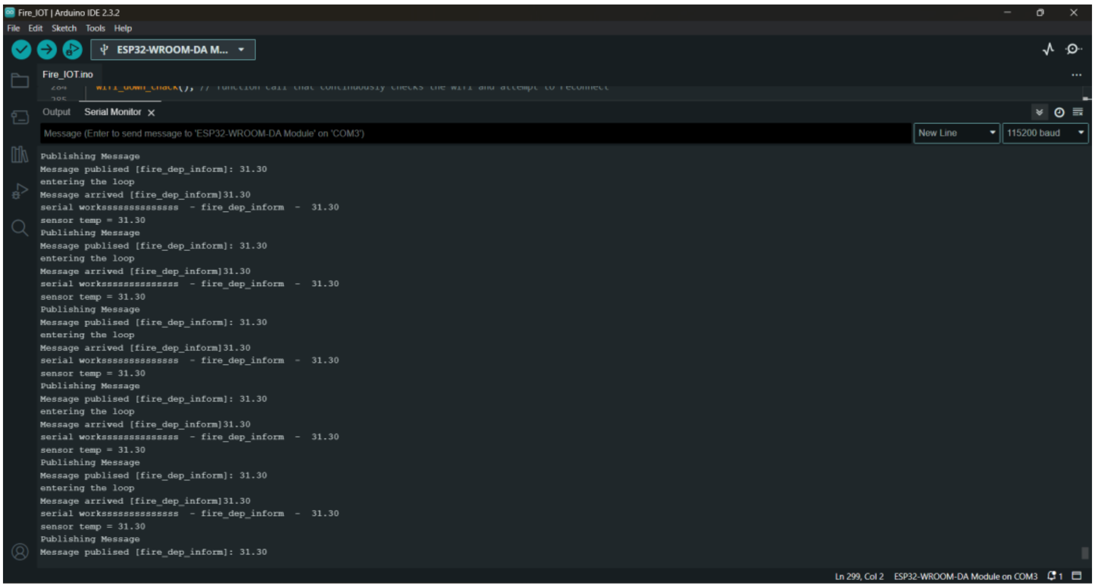


Figure 26 System Monitor the vehicle parameters to predict the fire

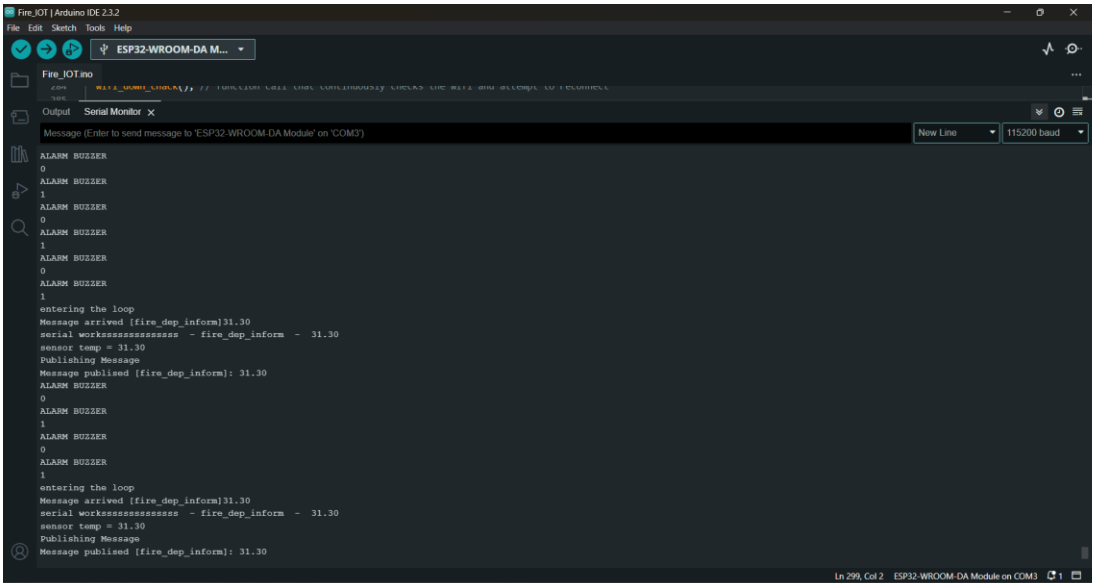


Figure 27 System responds after detecting the parameters and predicting the fire occurrence

3. RESULTS AND DISCUSSIONS

3.1. Results

The implementation phase saw the seamless integration of hardware and software components, ensuring the system performed as intended. The following advancements contributed to its functionality

- Sensors: Precision-based sensors capable of detecting heat, smoke, and other fire indicators were embedded within the system. These sensors ensured accurate and timely detection of potential fire hazards.
- Arduino Mega Microcontroller: The robust and programmable Arduino Mega served as the central controller, interfacing with the sensors, solenoid valves, and communication modules. Its reliability facilitated smooth coordination among all components.
- Modular Design: The integration process emphasized modularity, allowing for scalability and maintenance. This ensured that the system could adapt to future enhancements without overhauling the existing architecture.

The deployment of an automated suppression mechanism proved crucial in validating the system's emergency response capabilities:

- Solenoid Valve-Based Suppression: The system utilized solenoid valves to deploy extinguishing agents precisely and swiftly upon detecting fire conditions. This minimized potential damage and ensured safety.
- Trigger Mechanism: The sensors relayed critical information to the Arduino Mega, which in turn activated the suppression system. This process occurred in milliseconds, highlighting the system's ability to respond rapidly in high-stress scenarios.

One of the standout features of the system was its ability to provide instantaneous communication between the vehicle, the mobile application, and emergency services,

- Integration with MQTT: The adoption of the Message Queuing Telemetry Transport (MQTT) protocol ensured low-latency and lightweight data transmission. This was pivotal for real-time updates and notifications.
- Mobile Application Connectivity: The system was paired with a user-friendly mobile app that displayed live data from the vehicle sensors. This allowed vehicle owners to monitor their vehicles remotely and receive immediate alerts in case of anomalies.
- Emergency Dispatch Coordination: The system extended its functionality by notifying nearby fire departments in real-time. This was facilitated through an optimized route-finding algorithm and location sharing, ensuring rapid deployment of emergency services.
- Dashboards for Emergency Services: The accompanying web-based dashboard provided a centralized interface for emergency responders, displaying vehicle fire severity, location, and required actions. This enabled quick decision-making and effective resource allocation.

Advanced vehicle fire safety and monitoring system demonstrated its effectiveness as a comprehensive solution for vehicle fire prevention and management. Its integration of state-of-the-art technology, real-time communication protocols, and emergency dispatch solutions positions it as a transformative innovation in automotive safety.

3.2. Research Findings

The flarepath project demonstrated the system's remarkable ability to respond swiftly in critical scenarios. From detecting the earliest signs of fire to initiating the suppression mechanism, the response time was significantly short, measured in milliseconds. This rapid response is crucial for preventing the escalation of vehicle fires, which can spread rapidly and pose a severe threat to safety. During controlled tests, the system consistently activated the suppression mechanism immediately upon receiving fire indicators, minimizing potential damage and enhancing passenger and vehicle safety. The quick action underscores the system's reliability and readiness to handle real-world emergencies.

The accuracy and reliability of the sensors deployed in the system, particularly the MAX6675 temperature sensor and the MQ2 smoke sensor, played a pivotal role in its effectiveness. The MAX6675 sensor provided precise temperature readings, enabling the system to detect even subtle spikes that could indicate the onset of a fire. Similarly, the MQ2 smoke sensor efficiently identified the presence of smoke particles, which often leads to fire. These sensors worked in harmony to ensure that the system accurately differentiated between false alarms and genuine threats, minimizing unnecessary interventions. Their performance in rigorous testing environments confirmed their suitability for integration into the advanced vehicle fire safety system.

The integration of Internet of Things (IoT) technology was a turning point of the project, significantly enhancing the system's functionality and real-time capabilities. The implementation of the MQTT protocol facilitated seamless, low-latency communication between the vehicle sensors, the central system, and connected devices such as the mobile application. This real-time monitoring and alerting capability ensured that vehicle owners and emergency responders were instantly notified of fire incidents. The ability to transmit live data efficiently not only improved user engagement but also enabled emergency services to prepare and dispatch resources rapidly. The IoT framework further allowed for scalability, paving the way for future enhancements, such as predictive maintenance and data analytics.

These findings highlight the system's effectiveness in addressing the critical challenges of vehicle fire safety. The combination of rapid response, high sensor accuracy, and efficient IoT integration ensures a comprehensive solution that prioritizes safety, reliability, and real-time functionality. These findings highlight the potential of the system to set new standards in automotive fire prevention and emergency management.

3.3. Discussion

System Reliability and Efficiency

The system’s design emphasizes both reliability and efficiency, making it a robust solution for vehicle fire safety. Extensive testing under various conditions demonstrated its ability to operate consistently, ensuring prompt detection and suppression of fire incidents. The integration of precise sensors, efficient communication protocols, and rapid suppression mechanisms contributes to its dependability in high-pressure scenarios. This reliability is particularly critical in emergencies, where every second counts, and the system’s ability to function seamlessly highlights its readiness for real-world deployment.

Improvement Over Manual Systems

One of the most significant advantages of this system is its ability to outperform traditional manual fire suppression methods. Automated solutions like this reduce the dependency on human intervention, which can often be delayed or prone to error during emergencies. By providing a faster and more reliable response, the system addresses a critical gap in fire safety management. Its automated nature not only enhances response times but also ensures consistent performance, removing the variability that often accompanies human-operated systems.

Challenges and Future Improvements

While the system has proven effective, there are areas where further development could enhance its capabilities. One key area for improvement is the inclusion of predictive capabilities powered by machine learning. By analyzing historical data and identifying patterns, future iterations could anticipate fire incidents before they occur, providing even earlier warnings. Additionally, expanding the sensor network to include advanced sensors for detecting several gases, vibrations, or other indicators could improve detection accuracy and broaden the system's coverage. These enhancements would further solidify the system's position as a cutting-edge solution in vehicle fire safety.

Commercial Viability and Adaptation

The system's success in controlled environments demonstrates its potential for commercial viability. Its automated design, reliable performance, and integration of IoT technology make it an attractive solution for widespread adoption. However, transitioning from a prototype to a market-ready product requires addressing several challenges. Compatibility with a diverse range of vehicle systems, adherence to industry standards, and compliance with regional and international regulations are critical for broader market integration. These steps, coupled with rigorous testing and refinement, would ensure the system meets the demands of commercial application and regulatory approval.

4. CONCLUSION

The development and implementation of the advanced vehicle fire safety and monitoring system with rapid emergency dispatch solutions have conclusively demonstrated the potential to significantly enhance fire safety in automotive environments. This project achieved its main objective by successfully integrating a network of sensors, a solenoid valve-based suppression system, and IoT connectivity to provide a comprehensive, automated response to fire incidents within vehicles.

The system's ability to detect and respond to fire hazards autonomously, without the need for human intervention, marks a significant advancement over traditional manual fire suppression methods. It not only ensures rapid suppression of fires but also enhances the safety of vehicle occupants by minimizing their exposure to fire-related risks.

Throughout the testing phase, the system exhibited high reliability and effectiveness in detecting and extinguishing fires under various simulated conditions. The integration of real-time communication technologies further ensured that all stakeholders, including vehicle owners and emergency services, were kept informed, facilitating quicker response times during fire incidents.

Future developments could focus on refining the predictive capabilities of the system to prevent fires before they occur and expanding its adaptability to different vehicle models and environments. This would involve leveraging advanced data analytics and machine learning techniques to analyze historical data and predict potential fire hazards.

Flarepath rapid Emergency dispatch solution not only fulfills its initial objectives but also sets the stage for future innovations in vehicle fire safety, potentially leading to widespread adoption in the automotive industry. This would contribute significantly to reducing the incidence and impact of vehicle fires, thereby safeguarding lives and property in an increasingly mobile world.

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6. APPENDIX