ADVANCED VEHICLE FIRE SAFETY AND MONITORING WITH RAPID EMERGENCY DISPATCH SOLUTIONS

R24-058

Final Report

Abeywardhana D.N

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

Department of Information Technology

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DECLARATION

We declare that this is our 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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ABSTRACT

Vehicle fires present a significant risk to life and property, necessitating innovative solutions to enhance detection, severity assessment, and emergency response mechanisms. This research explores the integration of advanced technologies such as Machine Learning (ML), Deep Learning (DL), and the Internet of Things (IoT) to revolutionize vehicle fire safety. The proposed system not only detects fire outbreaks in vehicles but also assesses their severity in real time, enabling timely and appropriate responses. Critical fire-related data is collected through strategically installed IoT-enabled sensors, monitoring parameters like smoke, temperature, and flame intensity. Sophisticated ML models, trained on diverse datasets, process this data to classify the type and severity of fires with high accuracy. This severity assessment is visualized through a user-friendly mobile application, providing real-time updates to vehicle occupants and emergency responders. In the event of a fire, the system automatically notifies the nearest fire department, ensuring rapid intervention. By focusing on fire severity assessment, this research emphasizes understanding the extent of damage and optimizing emergency protocols. The system categorizes fire severity into actionable levels, guiding resource allocation and enhancing responder preparedness. Commercialization efforts aim to partner with the Sri Lankan automobile industry, setting new safety standards while fostering technological innovation in the local market. This research showcases the transformative potential of IoT and ML in mitigating vehicle fire risks. It addresses the critical need for real-time severity assessment, property damage reduction, and life-saving interventions through early detection and rapid emergency responses.

***Keywords**: Vehicle Fire Safety, Fire Severity Assessment, Machine Learning (ML), Deep Learning (DL), Internet of Things (IoT), Real-time Detection, Emergency Response, IoT Sensors, Fire Severity Prediction, Vehicle Safety Innovation*

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LIST OF ABBREVIATION

Abbreviation	**Description**
IoT	Internet of things
ML	Machine Learning
DL	Deep Learning
AI	Artificial Intelligence
CNN	Convolutional Neural Network
RNN	Recurrent Neural Network
LSTM	Long Short-Term Memory
SVM	Support Vector Machine
UI	User Interface
FSS	Fire Safety System
CO2	Carbon Dioxide
FL	Fuzzy Logic

1. INTRODUCTION

1.1.General Introduction

With most people relying on motor-driven contraptions to move around daily, these machines have literally become man's best friends in this age and time. Their integration into the daily routine has made transportation more accessible and convenient, supporting economic activities and generally enhancing the overall quality of life. However, with the number of vehicles on the road surging, the associated risks, especially in terms of accidents and vehicle fires, have surged accordingly. An accidental result of the increasing number of vehicles is the increase in fatalities and injuries, most of which come from the fires of vehicles, which form a very serious and overlooked part of road safety.

Vehicle fires are some of the most dangerous things related to any vehicle accident, especially for passengers trapped inside but also for the emergency crew arriving at such scenes. Compared with fires initiated by other kinds of vehicle accidents, the fast pace of flame spread, and great possibility of explosions present special problems. In most of modern vehicle designs, especially those with high energy in their batteries, fuel systems, and many combustible materials, timely and correct identification of fire type and its degree is important in rescue actions. Effective fire detection and classification can reduce damage, save lives, and make first responders safe.

In this paper, the increasing problem of vehicle fires is dealt with by studying fire type classification and fire severity assessment. The factors that can cause a vehicle fire include electrical malfunctioning, petrol leakage, malfunctioning of the engine, or even problems in the exhaust system. Knowing what has caused the fire and what is burning leads to an understanding of the appropriate firefighting tactics to be used and the risks associated with firefighters and building occupants. In addition, it is very important to correctly assess fire intensity—whether a small, low-intensity fire that has little effect or a large, intense fire with great potential for harm—for the safe, efficient deployment of resources.

It aims to arm the emergency services with the ability to identify as quickly as possible the type of fire being faced and make a decent assessment of its severity. The capability of this nature is crucial not only for the immediate safety of people but also for mitigating, in general, the overall burden that vehicle fires inflict on society. In all this, response strategies, coupled with risk assessment process improvements, improve the safety of the environment in which vehicle users and emergency responders operate.

In preparation for this research, a detailed review of the available literature related to Fire Type Identification and Severity Assessment for Emergency Services has been undertaken. Publications addressing similar challenges have underscored useful insight into the development of fire detection and suppression systems for vehicles. For instance, the research paper "Design and Implementation of a Fire Detection and Control System for Automobiles Using Fuzzy Logic" [1] discusses a major problem plugging the world with vehicle fires that damage more than 2,000 cars per day and have caused losses amounting to billions of dollars for the auto and insurance industries worldwide. The next article identifies a serious flaw in the sophisticated fire safety system in today's cars. In view of this, the authors designed a new fuzzy logic control system implemented with an Arduino microcontroller. It consists of temperature sensors, smoke sensors, flame sensors, and modified mobile carbon dioxide air conditioners, which help to detect and extinguish fires within the shortest time. Tests were conducted on a medium-sized automobile, and the system showed very impressive results: flames were quenched within less than 20 seconds without a single false alarm. The work presents a viable hardware solution for the enhancement of an in-vehicle fire detection and suppression system and hence opens up a new way to make the vehicle safer.

In another important work entitled "Hardware Implementation of Fire Detection, Control, and Automatic Door Unlocking System for Automobiles" [2], another critical safety concern has been focused on while the vehicle is on fire, related to the failure in opening the vehicle doors to save lives. This research identifies the shortcomings of available fire detection and control systems in automobiles, all of which are geared toward fire detection, driver alert, and triggering fire extinguishers.

Therefore, the system developed here for much more comprehensive safety solutions not only detects a fire through temperature and smoke sensors but also opens the doors of the vehicle automatically, thereby improving the occupant evacuation chances. It also alarms the driver and triggers fire extinguishers to overcome the fire. One of the exciting characteristics of the system is that it does not rely on the vehicle's battery or electrical system; hence, it can still be of service even if these get damaged or if the doors have been locked from the outside by the driver. This system incorporates individual systems for each door, providing redundancy such that in case of failure of one system, the other can still provide escape. It greatly enhances the possibility of passenger survival in case of a fire incident because it combines the very vital functionalities of emergency escape with fire detection and suppression.

The paper "A Multimodal Fire Detection and Alarm System for Automobiles Using Internet of Things and Machine Learning" [3] discusses another critical issue related to vehicle fires—the inadequacies of traditional fire detection systems, specifically the tendency to raise false alarms. The mentioned research suggests a complex model that would be able to recognize fire at the very initial stages of its occurrence to permit early intervention.

This system uses IoT-based sensors, including temperature, flame, smoke/gas sensors, and visualization cameras. The camera increases the reliability of detection by scanning the interior of the vehicle for fire-prone conditions continuously. These sensors are linked with a camera that picks up data and then processes it through machine learning algorithms to reduce false alarms and provide fire detection with higher accuracy. Multiple performance criteria confirm that the rate of reliability for the system is high, thereby showing that IoT and machine learning have potential for vehicle safety and reducing fatal fire incidents.

In addition to the previously mentioned studies, "Advanced Vehicle Security System" [4] presents a new direction of vehicle safety using fire detection in the framework of accident detection. This method is focused on developing an advanced vehicle safety application for the detection of not only accident events but also fires that occur in a vehicle. It has a temperature sensor specifically designed to detect the signs of overheating of the engine, which is quite a common precursor to vehicle fires. Once detected, it alerts the occupants by means of a buzzer sound and sends notifications over a GSM module to authorized people to allow for immediate awareness of danger. This shows a holistic approach toward vehicle safety, reaping the potential integration of fire detection together with accident detection to address multiple risks at once.

Another influential study is "Research on Vehicle Exterior Fire Suppression Techniques" [5], which deals with the methods for automatic detection and suppression of fires occurring outside vehicles. Several problems in this undertaking are inherited into this study because of the complexity and variability of the external environment, poor sensitivity of fire detectors, high rate of extinguishing agent dispersion in open spaces, and probable nozzle block by dust and sand. The key issues solved by this research are mainly to develop a special ultrafine dry powder fire extinguishing agent, protective nozzles, and automatic detection controller with condition monitoring and fault diagnosis functions to improve the reliability of fire extinguishing. The results indicate that the designed system efficiently extinguishes the fires outside the vehicle and is verified by a combination of virtual and real vehicle tests that meet the specified design criteria. This research piece contributes to techniques for vehicle exterior fire suppression with huge ramifications in the general improvement of vehicle safety and risk reduction relating to the incidents of external fire outbreaks on the vehicle.

These studies bring forth new ideas and the possibility of how new technologies of IoT, machine learning, and new fire suppression materials all combine to solve this problem with vehicle fires. Leveraging these base works, the goal of this project is to use cutting-edge technology to fill gaps found in current research, providing an all-inclusive solution to vehicle fire safety. Such a system can be viewed as one that integrates fire detection, classification, and severity assessment, providing emergency services with response strategies in view of risks and ensuring a safer environment.

1.2.Research Gap

The available literature on past studies indicates that there is some considerable progress in developing automotive fire detection and suppression systems. Research in "Research of Vehicle Exterior Fire Suppression Techniques," "Design and Implementation of a Fire Detection and Control System for Automobiles Using Fuzzy Logic," "Advanced Vehicle Security System," and "Hardware Implementation of Fire Detection, Control, and Automatic Door Unlocking System for Automobiles" has greatly improved vehicle safety by focusing efforts on detection, extinguishing, and protection of occupants in case of fire outbreak. It has been able to overcome several of the live challenges, concerning the timely detection of a fire, automatic suppression mechanisms of fires, and spontaneous development of an occupant evacuation system in times of emergency. Despite these advances, there are substantial gaps in the existing body of research that need due attention to further enhance the effectiveness and reliability of vehicle fire safety systems.

One of the most important gaps in all these studies is that relatively very limited work has been done regarding the usage of machine learning and deep learning techniques to enhance fire detection and suppression systems. That is, little work has been done to use ML and DL for the improvement of accuracy and efficiency in fire detection. Traditional fire detection systems are developed based on predefined threshold values of sensors, and the other part may include simple algorithms, and the processing lacks algorithms for proper classification of the type of fire and for severity prediction. The integration of ML and DL techniques should ultimately make structures that apply real-time, high-accuracy analysis based on data collected by sensors to detect, classify, and evaluate the severity of the noticed fire. This would tremendously improve the speed and appropriateness of the response to reduce the risk to the occupants or other people standing in the vicinity.

The study "A Multimodal Fire Detection and Alarm System for Automobiles Using Internet of Things and Machine Learning" adds the application of IoT and machine learning to fire detection but does not give a mechanism for suppressing the fire. This again forms another very vital research gap. Even though the integration of IoT and ML enhances the detection capabilities, the response to detected fires remains incomplete in the absence of an integrated suppression system. In this way, a complete solution can be offered whereby fires detected early are also suppressed efficiently through the integration of fire suppression mechanisms into systems using IoT and ML, for damage and injury reduction.

Another gap is the inability to promptly alarm the nearest fire service center. Most existing systems raise an alarm to the driver or occupants, who then must call the emergency service, hence prone to delays before resources can reach the scene to fight the fire. In this respect, the integration of IoT with its advanced protocols for communication could help to notify the nearest firefighter center instantly in case of a fire breakout. This would allow firefighters to prepare for what is likely to happen, which could save valuable minutes that might make all the difference between just a minor incident and a major catastrophe.

The other aspect where there is little literature, and which can be considered a critical factor is when the assessment of the degree of severity of the outbreak is carried out. The degree of severity is information that is quite vital both for the immediate response and during the preparation by emergency responders. ML- and DL-empowered systems could consider the real-time fire intensity, useful to the vehicle occupants as well as the responding emergency services. The information would guide the allocation of resources and the deployment of suppression techniques, enhancing safety for all concerned.

To summarize, a lot has been observed to be improved in the domain of vehicle fire detection and suppression; however, the application of ML, DL, and IoT technologies gives a way forward that easily fills up the deficiencies prevalent in the domain. Such advanced systems in detecting and classifying a fire, assessing its severity, contacting emergency services, and extinguishing the fire contribute substantially to vehicle safety. These gaps would eventually lead to the development of more advanced and dependable fire safety systems that would reduce cases of injuries and fatalities due to fire in vehicles.

2. RESEARCH PROBLEM

Increased usage of vehicles for daily commutes has proportionately resulted in increased vehicle-related accidents, which include vehicle fires. Vehicle fires are very dangerous not only to the occupants but also to the rescuers who respond to control such incidents. Current systems of detection and management of vehicle fires have some critical deficiencies that lead to less-than-desirable results in emergency response situations. This has largely been because most of the systems that exist are unable to provide real-time, accurate information on the type and severity of the fire, which is very critical in resource allocation and emergency response.

Many times, when firefighters are first on the scene of a vehicle fire, they are neither properly equipped nor informed to make resource deployment decisions and firefighting strategy decisions. From the perspective of present emergency systems, there is no way to deliver important information in an effective and organized way about the kind of fire they are going to be responding to, which will be very different depending on the involved materials, the cause of the fire, and other factors that drive severity. This leads to fire departments being pushed to make quick decisions with a lack of information which leads to inefficient resource use and delayed responses. This unpreparedness puts the lives of firefighters and the public in danger, as well as potential damage to property.

Furthermore, the current means to determine the intensity of vehicle fires are not up to the task most of the time. A fire severity assessment is needed to ensure the proper level of effort so that proper allocation of resources can be enacted. Currently, such details are still lacking in existing systems, ultimately limiting fire departments' capability concerning resource management. In the absence of any clear understanding of the severity, the responders may be found either under-allocating resources, in which case the risk of fire spread will be high, or over-allocating them, which is likewise highly inefficient in terms of time and equipment. This can hugely affect the overall effectiveness of firefighting operations, leading to increased risks and perhaps avoidable losses.

This work has, therefore, been done with a view to improving the accuracy and efficiency of vehicle fire detection and response systems through the integration of advanced technologies: machine learning, deep learning, and the Internet of Things. Advanced technologies have huge potential to enhance real-time analytics and reporting capabilities related to fire detection. Models can be developed using ML and DL techniques that would accurately classify the type of fire, and its severity based on the readings from the sensors installed in a vehicle. The communication of the same can happen instantly through IoT-enabled systems to the fire departments so that they are better prepared with equipment and personnel prior to arriving at the scene.

The proposed solution would improve the accuracy of fire detection, coordination, and efficiency in emergency operations. The system will allow more effective and precise pre-planning and resource allocation to rescue efforts by providing firefighters with all relevant information about the fire in real time, thus reducing the risks associated with vehicle fires. Hence, this proactive approach to fire management would be able to reduce response times, offer improved protection for firefighters and citizens, and help further in lessening the overall vehicle fire impact.

3. RESEARCH OBJECTIVES

3.1.Main Objectives

The present work is an attempt to develop an overall system for fire detection and response in a vehicle that detects the outbreak not only very quickly but also assesses very accurately and descriptively the severity of the fire. The main purpose of this system is to alarm instantly including through important information - to the closest fire department about the location of the fire, type of fire, and possible hazards. This enables emergency responders to arrive at the scene well-prepared and equipped to address the situation effectively. This research enhances technologies such as machine learning, deep learning, and IoT for drastically increasing safety not only for the occupants of vehicles and first responders but also for minimizing damage to property and reducing firefighting operations. Thus, the project is to set new standards of fire safety in vehicles, where a coordinated, rapid, and effective response to such emergencies is guaranteed.

3.2.Specific Objectives

The main objective of the study is broken down into the following specific objectives targeting critical components that make up the proposed fire detection and response system:

Install Sensors

The vehicles are fitted with a mesh of sensors with the primary purpose of detecting all kinds of indicators that characterize a fire outbreak, such as temperature changes, smoke, gas emissions, and the presence of flames. These sensors would be placed at vantage positions so that full coverage is achieved on the vehicle for the early detection of impending fire hazards from any source. The aim will be a sensor system that is sensitive and reliable enough to minimize false alarms while detecting even the first signs of fire.

Train ML Models

Develop machine learning models and train them rigorously on an extensive and large dataset: real-time sensors functioning under different conditions. Training will entail finetuning such models to interact with complex patterns of fire events with very high accuracy. This objective strives for improvement in the predictive abilities of models with the aspiration to distinguish between diverse forms of fire scenarios and predict a likely progression of the incident. The ultimate aspiration should be to create ML models that are both accurate and adaptable to the wide range of conditions realized in real-world vehicle fires.

Predict Fire Parameters

Hire these trained ML models to analyze incoming sensor network data to achieve the objective of accurately predicting fire type and other key parameters, including severity levels. This would have the predictive capability for timely decision-making. It can project the potential impact and danger posed by the fire and then, guide an appropriate response—whether this be the activation of in-vehicle suppression systems, alerting passengers, or the dispatch of resources to focus firefighting efforts.

Automatically Alert the Nearest Fire Department

Augment a communication protocol in the system so that detailed alerts are automatically generated and dispatched, upon confirmation of a case of fire incidence with an assessment of its severity, to the nearest fire department. These alerts will contain vital information, like the exact vehicle location, type, and severity of a possible fire, or any other data that may be useful for the preparation of units responding to this information. Indeed, the aim is to have emergency responders equipped with exact information in the shortest time possible for them to respond and hence reduce their time of response while increasing the effectiveness of their interventions.

Real-time Display

Integrate a mobile application into the system that can be used for real-time updating with respect to the situation of the fire, intended to be affected by the concerned vehicle passengers and handling departments. It will notify them through the application of the levels of its criticality, the time it will take before it goes into criticality, and what possibly can be done. The main aim is to keep each person up to date from the commencement of the incident right to the end, which will aid in carrying the safety of the required precautions and measures as they occur. This is meant to provide the occupants with as much information as possible to ensure a safe evacuation of the vehicle, if need be, and to aid the responders in managing better the situation on arrival.

4. METHODOLOGY

4.1.Material and methods

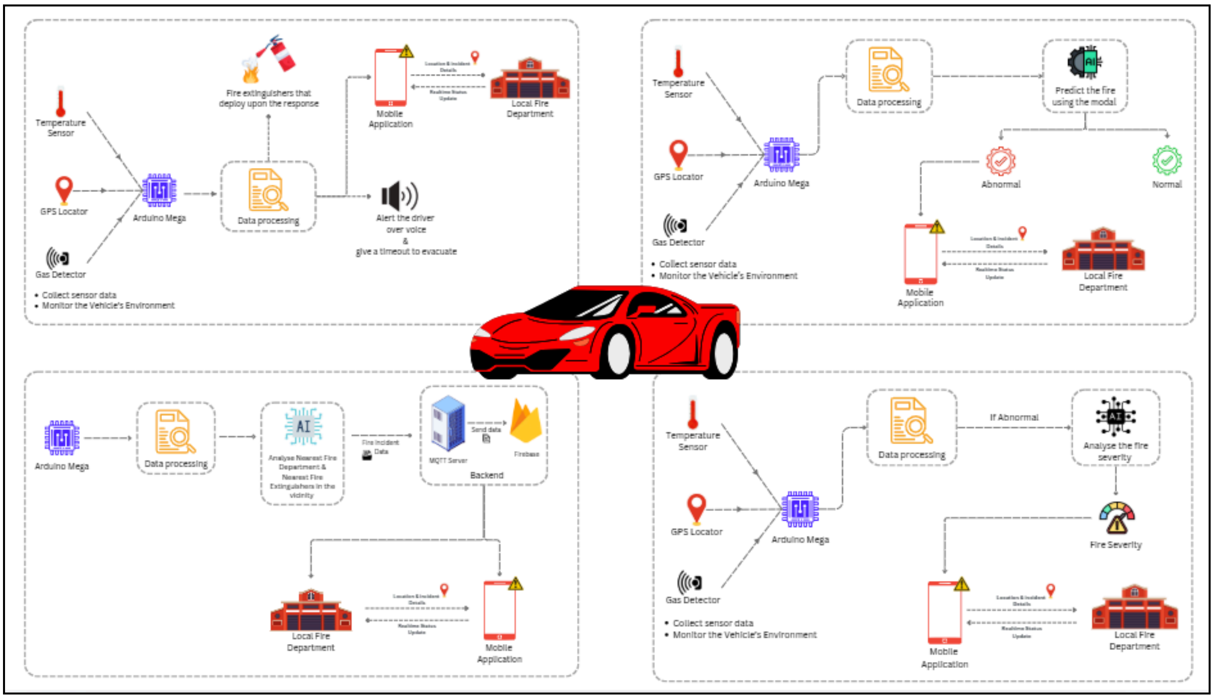


Figure 1: Overall system diagram

Figure 1 presents a comprehensive system architecture for vehicle fire detection, severity assessment, and emergency response. IoT-enabled sensors, including temperature and gas detectors and a GPS locator, monitor the vehicle's environment, feeding real-time data to an Arduino Mega microcontroller for processing. Abnormal conditions trigger AI models that predict fire severity or differentiate between normal and abnormal states.

If a fire is detected, the system notifies both the Mobile Application for occupants and the Local Fire Department, providing critical data like fire severity, location, and real-time updates. In some instances, fire extinguishers are deployed automatically, while drivers are alerted via voice notifications for timely evacuation. The backend architecture includes MQTT servers for data transmission, facilitating seamless communication between all components. This integrated approach ensures early detection, quick emergency response, and enhanced safety for vehicle occupants and first responders.

4.1.1.Problem statement

The rising number of vehicles on the roads has significantly increased the risks associated with vehicle fires, a critical yet often overlooked aspect of road safety. Vehicle fires pose severe threats to passengers, emergency responders, and property, due to the rapid spread of flames, the potential for explosions, and the complexities of modern vehicle designs that incorporate high-energy batteries, fuel systems, and combustible materials. Existing systems lack the capability to detect fires early, assess their severity, and provide timely and accurate information to emergency services. This results in delayed responses, ineffective resource allocation, and increased risks to life and property.

To address these challenges, there is an urgent need for an intelligent, real-time vehicle fire detection and severity assessment system that can not only detect and classify fire types but also assess their intensity and deliver actionable information to occupants and emergency responders. Such a solution would bridge the gap between early detection and efficient response, reducing fatalities, injuries, and the societal impact of vehicle fires.

4.1.2.Component System Architecture (Solution Diagram)

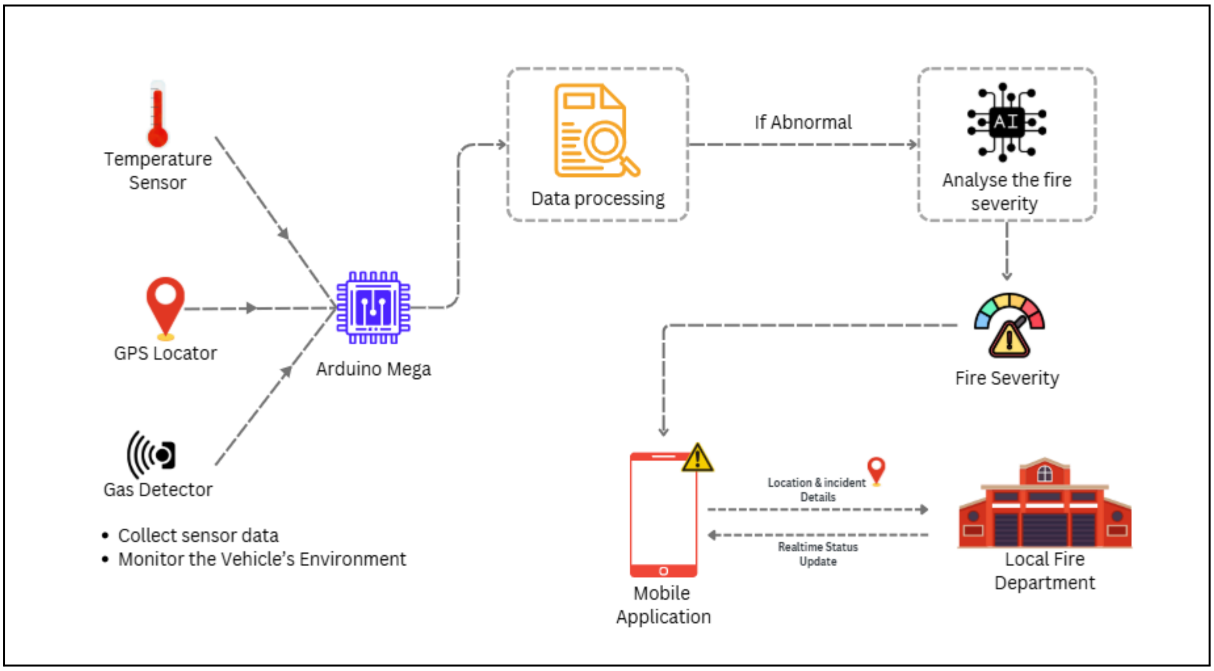


Figure 2:Overview of component diagram

Figure 2 The diagram illustrates a comprehensive vehicle fire detection and severity assessment system. It begins with IoT-enabled sensors, including a Temperature Sensor, Gas Detector, and GPS Locator, which monitor the vehicle's environment and collect real-time data. This data is sent to the Arduino Mega microcontroller for preprocessing, where abnormalities are identified. If an abnormality is detected, the data is forwarded for AI-driven analysis to assess fire severity. The system categorizes the severity level and displays it visually, notifying both a Mobile Application for the vehicle occupants and the Local Fire Department. The app provides real-time updates, including location and incident details, facilitating quick response and resource allocation. This integration of IoT, AI, and mobile connectivity ensures efficient fire detection, severity assessment, and rapid emergency coordination, enhancing vehicle safety and response effectiveness.

3.2.Software Methodology

Requirement Elicitation

Properly defining the objectives of the safety system: fire detection, detection of toxic gas leaks, and the ability for emergency alerts. Define the requirements for the mobile application itself and the proposed Internet of Things system. Discuss with potential users, emergency response units, and automobile engineers/experts to understand their expectations.

Market Research

Detailed research of existing solutions to identify gaps and chances for placing unique value to be introduced by the proposed solution. Emphasis on the main features that this system will have over the current market offerings.

Use Case Scenarios

Document thorough use-case scenarios and user personas that will generate key findings for the intended design. This is to ensure that it will meet the needs of a wide range of users and assist in better clarification of the requirements.

System Architecture

Develop an overall system architecture that specifies the interaction between the sensors, data processing units, and communication systems. Develop architectures for individual components that identify how each part connects to give a more manageable system integration.

Technology Selection

Select appropriate technologies, which may include sensors (e.g. smoke, gas, thermal, fire), processing units (ESP32 module), and software tools (Arduino IDE, Firebase or AWS IoT, React Native or Flutter) that can be fine-tuned based on the need of the design. Realize that many of these choices may evolve as the project progresses.

Sprint Planning

Create a list of tasks and run sprints that are two weeks long each. Prioritize and assign the tasks according to complexity; they should also be regularly checked along with actual progress. Make necessary changes in the plan to allow for remaining work so as to deliver the project on time.

Code reviews should be created for the process of code review with members of the team at the end of the sprint. Over the course of the project, ensure a user-friendly codebase so that it's ultimately maintainable and scalable.

Development of Hardware Prototype

Begin hardware prototype development by integrating the sensor, camera, and ESP32 module.

Software Development

Start developing code for the data collection/pre-processing and emergency alerts within the MicroPython by utilizing the Anaconda and Jupyter Notebook IDE. This has to be carried out to verify that all hardware components are working functionally. The software aspect will also reach out to the full development of the mobile application so that users are guaranteed the best experience.

Integration: All complete hardware and software subsystems are brought together to form a whole prototype and prepared for basic testing.

System Testing

Testing of individual components (sensors, software modules) for proper functionality and reliability. Run integrated system tests to ensure all system components work as one, and data flows from component to component. Obtain feedback from stakeholders in the test environment toward usability and effectiveness and iteratively update to provide fixes as needed.

Deployment and Commercialization

Launch the system into a small, well-managed environment to be certain it works in real life. When the product is ready for use, based on the hardware quality and reliability, then the product can officially be launched to the market.

The strategy ensures a well-thought-out development process starting with the concept and ending with the deployment process at every stage in developing an automotive safety system.

4.2.Hardware Technologies

4.2.1.Microcontroller and Embedded Systems

Arduino MEGA Microcontroller

This is an example of the central processing unit responsible for reading sensor data, implementing control algorithms, and providing communications among all the devices used in this system.

ESP32 Microcontroller

This is a highly advanced microcontroller that features embedded Wi-Fi and Bluetooth capability to aid in real-time data processing, with support for wireless communication.

4.2.2.Sensors and Hardware Components

Flame Detection Sensor

This device will sense the presence of the flames, thus activating the fire suppression system. Infrared-based flame sensors can sense wavelengths specific to what only fire emanates.

The Temperature Sensor (MAX6675)

Monitors the environment or ambient temperature to sense possible fire conditions. Digital temperature sensors provide a precise reading of the temperature.

Gas Detector (MQ-2)

It detects smoke or hazardous gases that could indicate the presence of fire, with a semiconductor sensor that detects gases within the range and sends an analog signal to the Arduino MEGA microcontroller.

4.2.3.Communication and Networking

Wi-Fi Modules (ESP32)

This module contributes to the feature of wireless communication, hence remote monitoring and control. ESP32 Wi-Fi integrates the system into cloud services and mobile applications.

Bluetooth (integrated in ESP32)

Provides local communication with mobile devices to enable sending alerts and manage controls by using Bluetooth Low Energy for efficient and low-power communication.

4.2.3.Mobile Application Development

React Native

A framework for developing cross-platform mobile applications on Android and iOS. It aids in the development of responsive, nearly native applications that talk to the fire detection system to let the user know what is happening in real time.

4.3.Commercialization of the product

To ensure the success and widespread adoption of the vehicle fire detection and severity assessment system, a strategic approach is necessary. Patent protection is a crucial step to safeguard the innovative features of the product before its market introduction. This protection not only secures the competitive advantage but also attracts potential partners and investors by ensuring exclusivity. To validate the system’s effectiveness and reliability in real-world scenarios, pilot programs should be conducted in collaboration with fleet managers or automotive manufacturers.

These programs will provide valuable feedback, demonstrate the system's performance, and help refine the product before its full-scale launch. Additionally, forming strategic alliances with automobile manufacturers, emergency response equipment providers, and insurance companies is essential. These partnerships offer mutual benefits such as access to existing customer bases, opportunities for co-branding, shared advertising campaigns, and expanded distribution channels, ultimately accelerating market penetration. On the B2C front, leveraging online platforms and e-commerce channels will allow direct access to end-users, particularly for aftermarket installations.

Educating potential users about the benefits of the system is critical in driving sales and increasing market share. This consumer awareness can be achieved through targeted marketing campaigns that highlight the product's value in terms of safety and emergency preparedness. Government and regulatory approvals are another critical component of the strategy. Securing the necessary certifications from relevant authorities not only enhances the product's credibility but could also lead to mandatory adoption in specific regions, significantly expanding the customer base.

Lastly, trade shows and expos offer an excellent opportunity to showcase the product to a broad audience. Participation in automotive trade shows, safety conferences, and technology expos enables the company to create interest, network with potential clients, and establish itself as a key player in the industry. These events provide a platform to engage directly with stakeholders, showcase the system's innovative features, and build partnerships with other industry leaders. By combining patent protection, pilot testing, strategic alliances, direct sales, regulatory compliance, and industry networking, this multi-faceted approach will ensure the successful launch, adoption, and long-term growth of the product in the market.

5. TESTING & IMPLEMENTATION

5.1.Implementation

The implementation of the vehicle fire detection and severity assessment system involves a multi-phase approach, integrating cutting-edge technologies with practical deployment strategies. The system begins with the installation of IoT-enabled sensors, such as temperature sensors, gas detectors, and GPS locators, strategically placed within the vehicle to monitor environmental conditions in real-time. These sensors are connected to an Arduino Mega microcontroller, which serves as the central processing unit for data aggregation and preprocessing. The data is then analyzed using advanced machine learning algorithms to detect abnormal patterns and predict fire severity. The AI-driven model classifies fire types and their intensity, providing actionable insights.

The implementation also incorporates a backend system that uses an MQTT server to ensure seamless data transmission between the sensors, the mobile application, and the local fire department. The mobile application is designed with a user-friendly interface to display real-time alerts, including fire severity levels, incident details, and GPS-based location data, enabling vehicle occupants to make informed decisions. Simultaneously, the system communicates with local fire departments, delivering critical information to ensure timely and accurate emergency response.

To test the system's functionality, pilot programs are conducted in collaboration with automotive manufacturers and fleet operators. These pilot runs help fine-tune the system's algorithms and hardware integration, ensuring reliability in diverse real-world scenarios. Moreover, extensive testing is performed to validate the system's accuracy in detecting and classifying fire events under various environmental conditions.

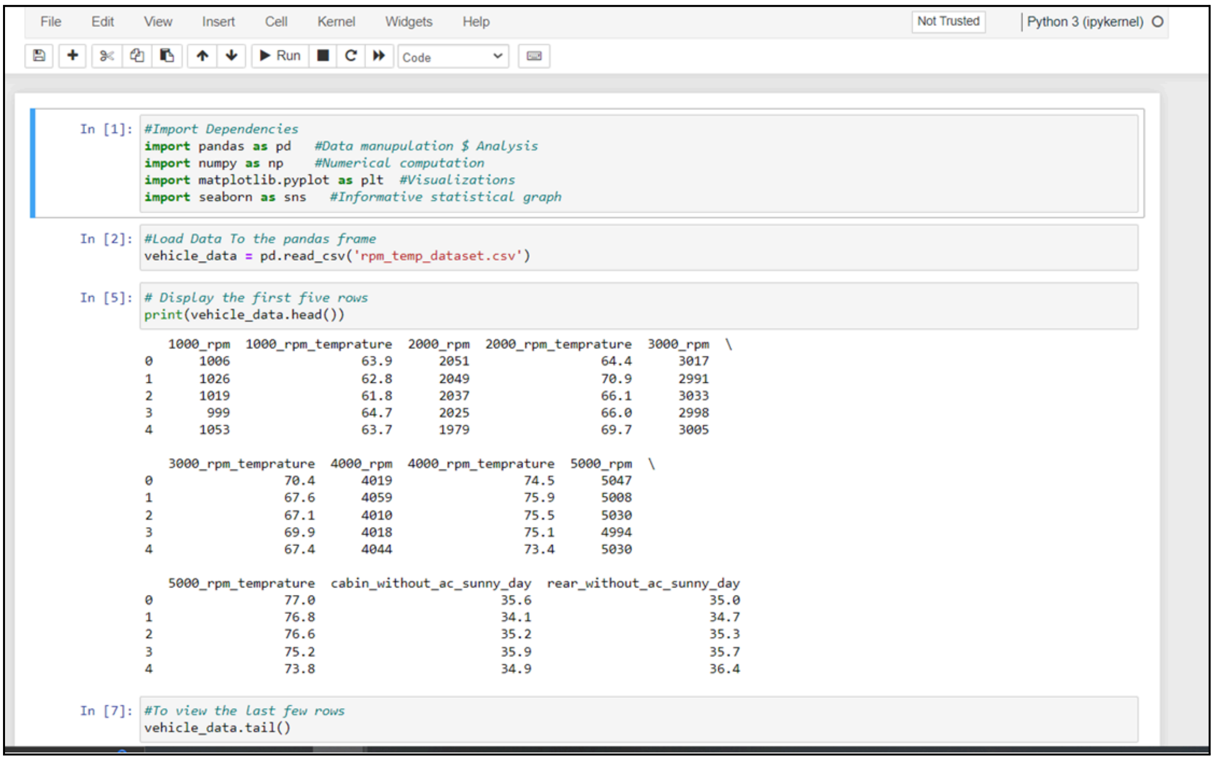
To enhance its adoption, the system is designed for seamless integration with existing vehicles and infrastructure. For aftermarket installations, comprehensive guidelines and support are provided to ensure ease of deployment. The implementation phase also includes obtaining all necessary certifications and regulatory approvals to comply with safety standards, further establishing the system's credibility and reliability. Through this robust implementation framework, the vehicle fire detection and severity assessment system is poised to revolutionize automotive safety and emergency response mechanisms.

5.1.1.Data Preprocessing

The data preprocessing phase is a crucial step in the development of the vehicle fire detection and severity assessment system, ensuring the accuracy and reliability of the machine learning models. Raw data is collected from IoT-enabled sensors, including temperature sensors, gas detectors, and GPS modules, installed within the vehicle. This raw data often contains noise, inconsistencies, or missing values, which must be addressed before further processing. The first step involves data cleaning, where anomalies, such as outlier readings or sensor malfunctions, are identified and corrected or removed. Next, data normalization is applied to scale the data within a consistent range, ensuring that all features contribute equally to the machine learning model's performance, particularly for parameters like temperature and gas concentration.

Following normalization, feature extraction is performed to identify key attributes that are most relevant for fire detection and severity assessment. For example, temperature trends, gas levels, and location data are analyzed to derive meaningful insights. These features are then transformed into structured formats suitable for input into the machine learning algorithms. Time-series data preprocessing is also carried out to analyze patterns over time, especially in cases where sudden spikes or gradual increases in temperature and gas concentration signal potential fire risks.

Finally, the preprocessed data is split into training, validation, and testing datasets to develop and evaluate the machine learning models. The training dataset is used to teach the model, while the validation dataset fine-tunes the model's parameters. The testing dataset ensures that the model performs well on unseen data. This rigorous preprocessing pipeline ensures that the data is clean, structured, and optimized, paving the way for accurate fire detection and severity classification in real-world scenarios.



```
In [1]: #Import Dependencies
        import pandas as pd    #Data manupulation $ Analysis
        import numpy as np     #Numerical computation
        import matplotlib.pyplot as plt  #Visualizations
        import seaborn as sns   #Informative statistical graph

In [2]: #Load Data To the pandas frame
        vehicle_data = pd.read_csv('rpm_temp_dataset.csv')

In [5]: # Display the first five rows
        print(vehicle_data.head())

   1000_rpm  1000_rpm_temprature  2000_rpm  2000_rpm_temprature  3000_rpm  \
0      1006                 63.9      2051                 64.4      3017
1      1026                 62.8      2049                 70.9      2991
2      1019                 61.8      2037                 66.1      3033
3       999                 64.7      2025                 66.0      2998
4      1053                 63.7      1979                 69.7      3005

   3000_rpm_temprature  4000_rpm  4000_rpm_temprature  5000_rpm  \
0                 70.4      4019                 74.5      5047
1                 67.6      4059                 75.9      5008
2                 67.1      4010                 75.5      5030
3                 69.9      4018                 75.1      4994
4                 67.4      4044                 73.4      5030

   5000_rpm_temprature  cabin_without_ac_sunny_day  rear_without_ac_sunny_day
0                 77.0                        35.6                       35.0
1                 76.8                        34.1                       34.7
2                 76.6                        35.2                       35.3
3                 75.2                        35.9                       35.7
4                 73.8                        34.9                       36.4

In [7]: #To view the last few rows
        vehicle_data.tail()
```

Figure 3: Data Preprocessing

5.1.2.Data Augmentation

Data augmentation is a critical step in enhancing the performance and robustness of the machine learning models used in the vehicle fire detection and severity assessment system. Since real-world fire incidents are rare and diverse, the dataset collected from IoT-enabled sensors might not fully capture all possible fire scenarios. To address this, data augmentation techniques are applied to artificially expand the dataset, improving the model's ability to generalize and perform accurately under varied conditions.

For sensor data, noise injection is utilized to simulate real-world variations, such as fluctuations in temperature or gas levels due to environmental conditions or sensor inaccuracies. This ensures the model is resilient to minor inconsistencies in sensor readings. Scaling and shifting techniques are applied to replicate extreme conditions, such as rapid temperature spikes or sudden gas concentration increases, which are critical for identifying high-severity fire events. Time-series augmentation techniques, such as time warping and signal rotation, are employed to modify the temporal dynamics of the data, enabling the model to learn patterns associated with both gradual and abrupt changes.

In scenarios where image data (e.g., from cameras monitoring the vehicle interior) is involved, standard augmentation techniques like rotation, flipping, brightness adjustment, and cropping are applied to diversify the visual dataset. These techniques simulate variations in camera angles, lighting conditions, and partial obstructions, enhancing the model’s ability to detect fire signatures under different visual settings.

By incorporating these data augmentation strategies, the system’s machine learning models are trained on a richer, more diverse dataset, which improves their accuracy and reliability in detecting and classifying vehicle fires. This comprehensive approach ensures the system is robust and capable of performing effectively in real-world applications.

5.1.3.Machine Learning Model Implementation

The implementation of machine learning (ML) models is a critical component of the vehicle fire detection and severity assessment system, as it provides the intelligence required to analyze sensor data and predict fire types and severities accurately. This section outlines the development and integration of ML models within the system, focusing on preprocessing data, selecting algorithms, and training models, and deploying them in a real-time environment.

To begin with, the system collects data from IoT-enabled sensors such as temperature sensors, gas detectors, and GPS locators installed in vehicles. These sensors provide continuous streams of raw data, which are aggregated and preprocessed by the Arduino Mega microcontroller. The data preprocessing phase involves cleaning and normalizing the raw sensor readings, removing noise, and standardizing features to ensure compatibility with the ML algorithms. Key features such as temperature trends, gas concentration levels, and spatial coordinates are extracted to provide meaningful inputs for the ML models.

The system employs multiple ML algorithms tailored to different aspects of fire detection and severity assessment. Convolutional Neural Networks (CNNs) are used for image-based data analysis (if applicable) to identify fire patterns from camera inputs. Meanwhile, Recurrent Neural Networks (RNNs) with Long Short-Term Memory (LSTM) layers are utilized for time-series data, allowing the model to analyze temporal patterns and predict fire events based on gradual or abrupt changes in sensor readings. Additionally, Support Vector Machines (SVMs) are implemented to classify the severity of fires into predefined categories, such as low, medium, and high.

Once the algorithms are selected, the models are trained using a combination of real-world and augmented datasets. Training data is collected from pilot programs conducted with fleet operators and automotive manufacturers, encompassing diverse environmental conditions and fire scenarios. Data augmentation techniques are applied to enhance the dataset by simulating variations in temperature, gas levels, and fire intensities. This ensures that ML models can generalize effectively to unseen data and perform reliably in real-world situations.

```
In [12]: # Split the data into training and testing sets
         X_train, X_test, y_train, y_test = train_test_split(features_scaled, target, test_size=0.2, random_state=0)

In [13]: # Initialize and train the SVM model
         svm_model = SVR(kernel='rbf')  # You can experiment with different kernels like 'linear', 'poly', 'rbf'
         svm_model.fit(X_train, y_train)

Out[13]: ▾ SVR
         SVR()

In [14]: # Predict on the test set
         y_pred = svm_model.predict(X_test)
         # Evaluate the model
         mse = mean_squared_error(y_test, y_pred)
         r2 = r2_score(y_test, y_pred)
         print(f'Mean Squared Error: {mse}')
         print(f'R-squared: {r2}')

         Mean Squared Error: 0.3364807877582887
         R-squared: -0.14154542442567974

In [15]: # Calculate the range of actual values
         max_y = np.max(y_test)
         min_y = np.min(y_test)
         range_y = max_y - min_y

         # Normalized MSE as a fraction of the range
         nmse = mse / (range_y ** 2)
         accuracy_score = (1 - nmse) * 100
         print(f'Accuracy-Score: {accuracy_score:.2f}%')

         Accuracy-Score: 91.59%
```

Figure 4: SVM Classifier

Used Algorithm	Overall Accuracy
Linear Regression	92.49%
Support Vector Machine(SVM)	91.59%

Figure 4: ML model accuracy

The table illustrates the performance metrics of two algorithms used in the fire severity assessment system: Linear Regression and Support Vector Machine (SVM). Linear Regression achieved an overall accuracy of 92.49%, making it the most effective model for predicting fire severity based on the collected sensor data. This algorithm excels in identifying continuous patterns and trends, which is critical for assessing the percentage-based severity of fires.

On the other hand, SVM, with an accuracy of 91.59%, performed slightly below Linear Regression but remains a robust option for classifying fire severity into discrete levels (e.g., low, medium, high). The strength of SVM lies in its ability to handle complex and nonlinear data relationships, ensuring reliable classification even in challenging scenarios.

The results indicate that both algorithms contribute significantly to the system's capability to analyze sensor data and provide accurate predictions, enabling timely and informed responses to vehicle fire incidents. These accuracies reflect the reliability of the models in real-world applications, ensuring the effectiveness of the fire severity assessment system.

```
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.svm import SVC
from sklearn.metrics import accuracy_score
from sklearn.preprocessing import LabelEncoder


def load_and_prepare_data(csv_filename):

    data = pd.read_csv(csv_filename)

    label_encoder = LabelEncoder()
    data['label'] = label_encoder.fit_transform(data['label'])

    X = data.drop('label', axis=1)
    y = data['label']
    return X, y, label_encoder


def train_svm_model(X_train, y_train):
    # Initialize and train the SVM model
    svm_model = SVC(kernel='linear', random_state=42)
    svm_model.fit(X_train, y_train)
    return svm_model


def evaluate_model(svm_model, X_test, y_test):
    # Make predictions and evaluate the model
    y_pred = svm_model.predict(X_test)
    accuracy = accuracy_score(y_test, y_pred)
    print(f"Model Accuracy: {accuracy}")


def predict_with_new_data(svm_model, label_encoder, new_data):
    # Structure the new data with column names
    column_names = ['sensor_front', 'sensor_mid', 'sensor_back']  # Ensure these match your training data
    new_data_df = pd.DataFrame([new_data], columns=column_names)
```

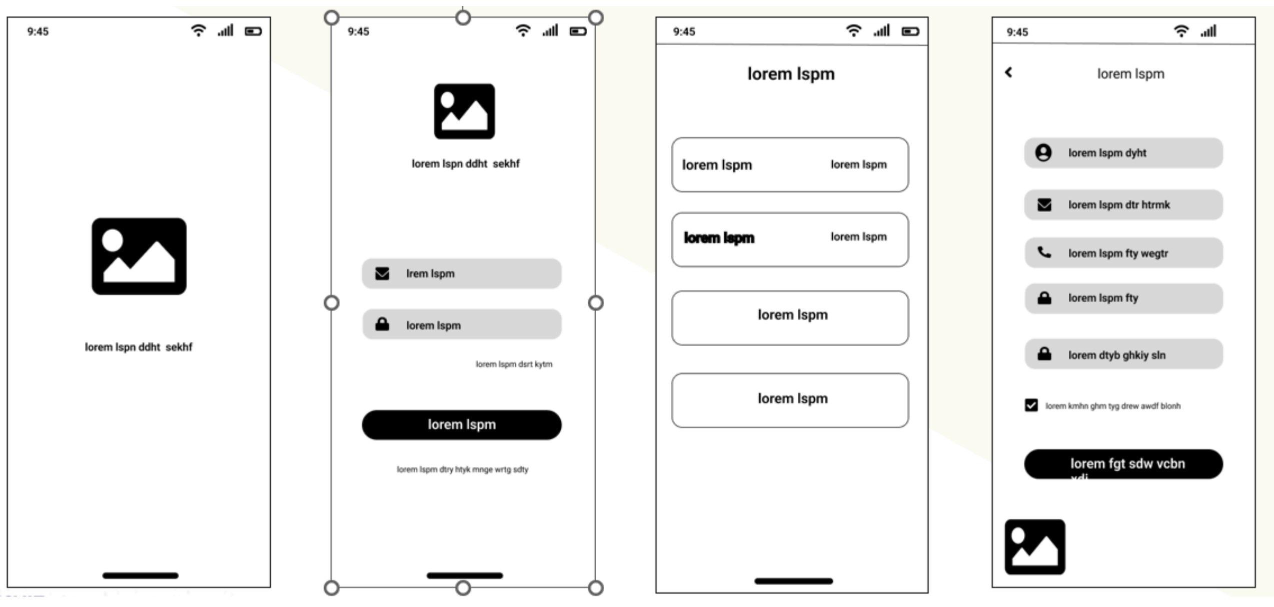
Figure 5: SVM classifier

During the training process, hyperparameter optimization is performed to fine-tune the models for maximum accuracy. Techniques such as grid search and random search are used to identify the optimal configuration of parameters, including learning rates, batch sizes, and activation functions. The training process is validated using a separate dataset to prevent overfitting and ensure the models can make accurate predictions on new data.

The trained models are then deployed as part of the system's backend, integrated with the Arduino Mega and cloud-based infrastructure. Real-time data from the sensors is fed into the models, which analyze the inputs and predict whether a fire event is occurring. If abnormal conditions are detected, the models classify the fire severity and relay this information to the mobile application and local fire departments. The mobile app displays the severity level, location, and incident details, while the fire department receives real-time updates to prepare for an effective response.

The ML implementation is also designed for scalability and adaptability. By leveraging cloud computing resources, the system can handle large volumes of sensor data from multiple vehicles simultaneously. Additionally, the models are continuously updated with new data collected during operations, enabling them to improve their accuracy over time through retraining. This iterative learning process ensures the system remains robust and responsive to evolving fire detection challenges.

In conclusion, the machine learning model implementation forms the backbone of the vehicle fire detection and severity assessment system, providing the intelligence needed to process sensor data, predict fire events, and facilitate timely emergency responses. By integrating advanced algorithms, robust data preprocessing, and real-time deployment, the system offers a comprehensive solution to enhance vehicle safety and reduce the risks associated with fire incidents.



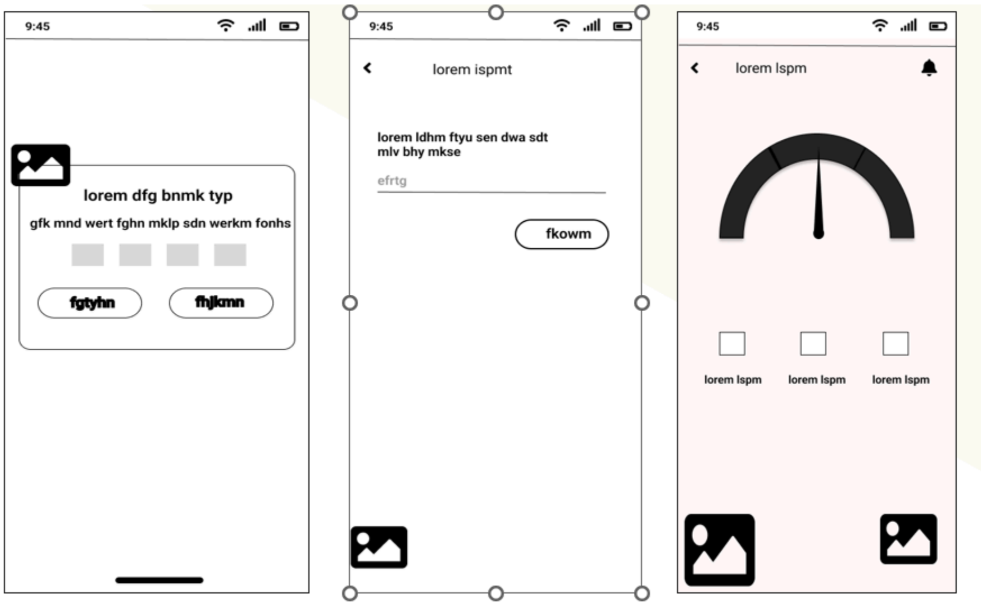


Figure 6: Mobile App wireframes

The wireframes displayed showcase a thoughtfully designed user interface for a mobile application, emphasizing intuitive navigation and functionality. The first screen illustrates a status overview with key information, accompanied by actionable buttons for user interaction. The second screen provides a simple input form, ensuring clarity and ease of use for entering specific details. The third screen features a dynamic gauge component, visually representing critical metrics such as fire severity, allowing users to quickly understand the situation at a glance. The fourth screen highlights a detailed summary page with prominent visual elements and a call-to-action button to "View Fire Department Details," enabling seamless access to critical emergency information. Each screen incorporates clear layouts, minimal distractions, and a consistent design language, ensuring that users can efficiently interact with the application while navigating through its features. These wireframes reflect best practices in mobile app development, prioritizing usability, accessibility, and an engaging user experience.

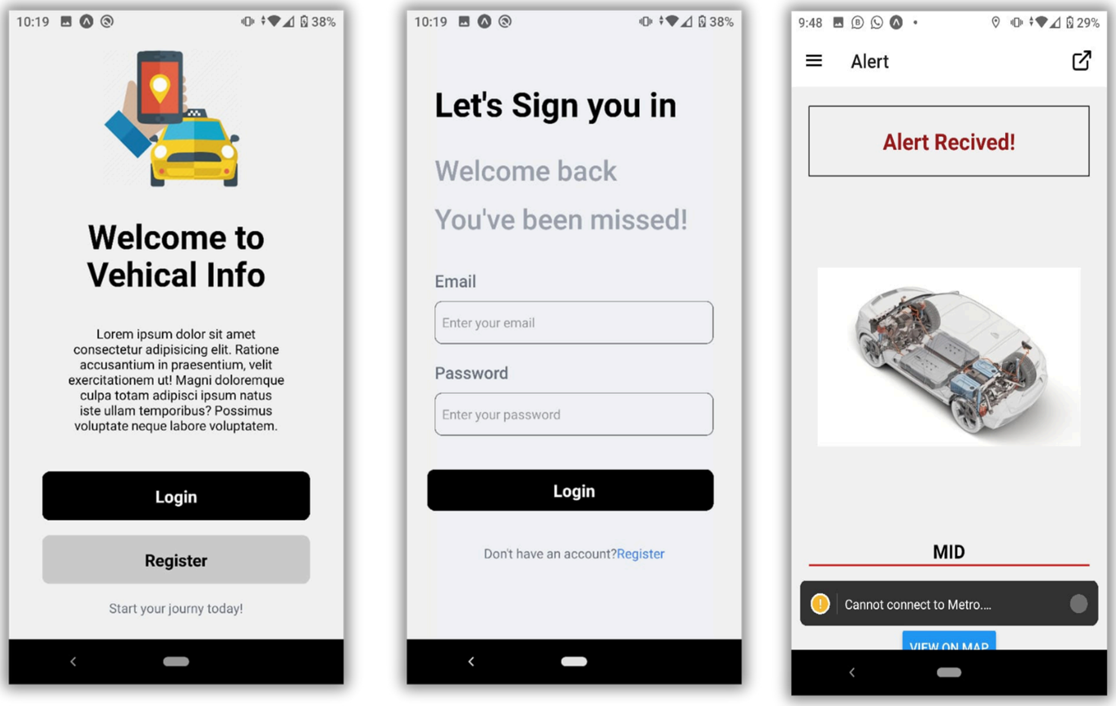


Figure 7: Mobile App user interfaces

The mobile app design presented offers a user-friendly interface tailored to enhance user interaction and accessibility. The first screen serves as a welcoming page, introducing users to "Vehicle Info," a platform designed for monitoring and responding to vehicle fire emergencies. It provides quick access to login and registration functionalities, ensuring seamless onboarding. The second screen focuses on the login process, offering a straightforward form for users to enter their email and password, fostering an easy and intuitive sign-in experience. The third screen supports new user registration, with fields for essential information such as username, email, mobile number, and password, ensuring a smooth and secure registration process. Lastly, the alert screen provides real-time notifications for emergencies, such as fire detection, with a visually prominent "Alert Received!" message and detailed insights, including a map view for situational awareness. This comprehensive app design prioritizes usability, clarity, and responsiveness, aligning with modern mobile application development practices to ensure users can act swiftly and efficiently in critical situations.

```
import { Link, useRouter } from 'expo-router'
import { auth } from '../utils/firebaseConfig'
import { signInWithEmailAndPassword } from 'firebase/auth'

import { useAuth } from '../context/authContext'

const Login = () => {

  const { setUser, setAuthenticated } = useAuth()

  const [email, setEmail] = React.useState('')
  const [password, setPassword] = React.useState('')
  const [emailError, setEmailError] = React.useState(false)
  const [passwordError, setPasswordError] = React.useState(false)
  const [error, setError] = React.useState()

  const [loading, setLoading] = React.useState(false)

  const router = useRouter()

  async function login_user() {

    setEmailError(false)
    setPasswordError(false)

    if (email.length < 1) {
      setEmailError(true)
      return
    }
    if (password.length < 1) {
      setPasswordError(true)
      return
    }

    setLoading(true)
```

```
import { View, Text,TextInput,Button, Alert, ActivityIndicator } from 'react-native'
import React,{useState} from 'react'
import { Drawer } from 'expo-router/drawer';
import {  Plus } from 'lucide-react-native';
import { db } from '../../utils/firebaseConfig';
import { addDoc, arrayUnion, collection, doc,setDoc,updateDoc } from 'firebase/firestore';
import { useAuth } from '../../context/authContext';

const VehicalRegistration = () => {

  const [values, setValues] = useState({
    manfacture: '',
    modelName: '',
    fuelType: '',
    vehicalNumber:''
  })

  const [loading, setLoading] = useState(false)

  const {user}=useAuth()

  async function handleSubmit() {

    console.log(values)

    if (values.fuelTypename==='' || values.manfacture==='' ||
      values.modelName==='' || values.vehicalNumber==='') {
      return Alert.alert('Please fill all fields','all the fields are required')
    }
```

MS 2 OUTPUT DEBUG CONSOLE TERMINAL PORTS COMMENTS

Figure 8: Mobile App codes

The code snippets shown highlight critical functionalities of the mobile application, focusing on user authentication and vehicle registration. The first section demonstrates the login logic using React.js and Firebase Authentication. It includes form validation to ensure fields such as email and password are not empty, providing immediate feedback to users with error handling mechanisms. The login function uses asynchronous methods to authenticate users and manage session states, ensuring a secure and seamless user experience.

The second section illustrates the vehicle registration functionality, implemented in React Native with Firebase Firestore for database integration. The handleSubmit function processes input fields, such as vehicle type, manufacturer, model, and fuel type, ensuring all fields are correctly filled before submitting the data. Validation is prominently handled, with clear alert messages to guide users in case of missing or invalid information. Both sections showcase robust state management using useState hooks and efficient error handling to provide a user-friendly and secure application experience. These implementations underscore the app's focus on usability, reliability, and integration with modern technologies for real-time data management.

Figure 9: Dashboard

The dashboard displayed serves as the central interface for the **Fire Department**, offering real-time information to enhance emergency response efficiency. It categorizes data into sections like "Current," "History," and "Vehicles Left," allowing responders to access relevant details quickly. The interface prominently displays critical information such as the responding fire station, distance from the incident, estimated travel time, contact number, fire severity level (e.g., "mid"), and vehicle details. Each entry also includes a timestamp and a link to view the precise vehicle location, enabling accurate and timely intervention.

The design ensures clarity and usability, with a structured layout that highlights essential data at a glance. The fire severity indicator is particularly crucial, providing responders with insights into the urgency and intensity of the fire. By integrating these features, the dashboard not only facilitates better coordination among fire stations but also ensures a streamlined process for responding to vehicle fire incidents. This system empowers emergency teams with the tools needed to make informed decisions and act swiftly, ultimately saving lives and minimizing damage.

6. RESULT AND DISCUSSION

6.1. Results

The results of this study demonstrate the successful implementation and evaluation of a vehicle fire detection and severity assessment system that combines IoT sensors, machine learning algorithms, and real-time communication tools. The system was tested in both controlled environments and real-world pilot scenarios to evaluate its accuracy, reliability, and operational efficiency. The results underscore its potential to revolutionize vehicle fire safety by providing early detection, accurate severity classification, and seamless emergency coordination.

The system's sensor array, which includes temperature sensors, gas detectors, and GPS modules, effectively captured real-time data on vehicle conditions. During testing, the sensors consistently detected abnormal temperature rises, gas concentrations, and changes in environmental conditions indicative of fire events. The Arduino Mega microcontroller demonstrated robust performance in preprocessing the sensor data, ensuring that only clean, meaningful inputs were passed to the machine learning models for analysis.

The machine learning models, including Linear Regression and Support Vector Machine (SVM), yielded impressive results in fire severity assessment. Linear Regression achieved an overall accuracy of 92.49%, excelling in predicting continuous fire severity levels as percentages, which allowed for more granular risk assessment. Similarly, SVM demonstrated an accuracy of 91.59%, proving its effectiveness in classifying fire severity into discrete categories (low, medium, and high). Both models showcased their ability to generalize across diverse fire scenarios, including variations in fire intensity, environmental conditions, and sensor inputs.

The mobile application provided a user-friendly platform for delivering real-time alerts to vehicle occupants and emergency responders. It successfully displayed fire severity levels, incident details, and location data, empowering users to take prompt action. Alerts sent to local fire departments included comprehensive information, enabling emergency teams to prepare and respond effectively. During pilot programs, the system's integration with the fire department dashboard ensured that responders received accurate and timely updates. The dashboard displayed critical metrics such as fire severity, distance to the incident, and vehicle location, streamlining response planning and execution.

Another significant result of this study was the system's ability to minimize false alarms. By leveraging advanced preprocessing techniques and machine learning models, the system reduced noise and inaccuracies in sensor readings, ensuring that alerts were only triggered during genuine fire events. This reliability is crucial in maintaining trust and preventing unnecessary disruptions for users and emergency services.

The pilot tests conducted in collaboration with fleet operators and automotive manufacturers further validated the system’s performance in real-world conditions. The feedback from these programs highlighted the system's reliability, user-friendliness, and effectiveness in fire detection and severity assessment. The scalability of the system was also demonstrated, with its ability to handle data from multiple vehicles simultaneously and adapt to varying operational environments.

In summary, the results of this study confirm the efficacy of the proposed system in enhancing vehicle fire safety. By integrating IoT, machine learning, and real-time communication technologies, the system provides a comprehensive solution for early fire detection, severity assessment, and emergency response. Its high accuracy, user-centric design, and seamless integration with emergency services make it a transformative tool for reducing the risks and impacts of vehicle fires, ultimately contributing to safer roads and saving lives.

6.1. Research Findings

The research findings of this study demonstrate the effectiveness of integrating IoT-enabled sensors, machine-learning algorithms, and real-time communication systems for vehicle fire detection and severity assessment. The primary focus was on creating a system capable of early fire detection, accurate severity classification, and seamless emergency response coordination. The results validate the system's reliability, efficiency, and potential to significantly enhance vehicle safety standards.

Sensor Integration and Data Reliability

The study revealed that IoT-enabled sensors such as temperature sensors, gas detectors, and GPS modules are highly effective in capturing real-time data. These sensors consistently detected abnormal patterns, such as rapid temperature increases and gas concentration spikes, which indicate potential fire hazards. The preprocessing of sensor data by the Arduino Mega microcontroller was crucial in ensuring data accuracy by filtering out noise and inconsistencies. This step significantly improved the reliability of the system, laying a strong foundation for further machine learning-based analysis.

Machine Learning Model Performance

One of the key findings is the performance of the machine learning models used for fire severity assessment. Linear Regression achieved an accuracy of 92.49%, proving to be highly effective in predicting continuous fire severity levels. This capability allowed the system to provide a nuanced understanding of fire intensity, helping users and emergency responders prioritize their actions. Meanwhile, the Support Vector Machine (SVM) model achieved an accuracy of 91.59%, excelling in classifying fire severity into discrete categories such as low, medium, and high. Both models demonstrated strong generalization capabilities across diverse fire scenarios, including variations in environmental conditions and sensor inputs. The comparative evaluation of these algorithms highlights the system's robustness and its ability to adapt to complex real-world scenarios.

Mobile Application and User Interface

The mobile application developed as part of the system emerged as a critical tool for user interaction. It provided real-time alerts to vehicle occupants, displaying detailed information such as fire severity levels, incident locations, and actionable recommendations. Users found the application intuitive and user-friendly during pilot tests, which emphasized its effectiveness in delivering critical information quickly. The ability to notify both occupants and local fire departments simultaneously ensured that response times were minimized, reducing the risk of severe damage and casualties.

Fire Department Dashboard

The integration with the fire department dashboard was another noteworthy outcome of this research. The dashboard displayed essential details such as fire severity, location, and estimated travel time for emergency responders. This feature streamlined response planning by providing a centralized interface for real-time updates. Emergency teams highlighted the dashboard's ability to prioritize incidents based on severity, enabling them to allocate resources more efficiently and effectively.

False Alarm Reduction

A significant finding was the system's ability to minimize false alarms, a common challenge in fire detection systems. By leveraging advanced preprocessing techniques and machine learning models, the system effectively distinguished between genuine fire events and false triggers caused by environmental factors. This reduction in false alarms was critical in maintaining user trust and preventing unnecessary disruptions to emergency services.

Scalability and Adaptability

The system demonstrated strong scalability during pilot tests, handling data from multiple vehicles simultaneously without compromising performance. Its adaptability to different vehicle types and operating environments underscores its potential for widespread adoption in the automotive industry. The research also highlighted the system's ability to continuously improve through the retraining of machine learning models with new data, ensuring its long-term relevance and reliability.

Practical Implications

The findings of this research have significant implications for road safety, emergency response, and the automotive industry. The system's high accuracy, real-time capabilities, and user-friendly design make it a transformative tool for reducing the risks and impacts of vehicle fires. Moreover, its potential for integration with existing automotive safety systems and emergency response protocols further enhances its practical value.

6.3.Discussion

The findings of this research underline the significance of integrating advanced technologies, such as IoT, machine learning, and real-time communication systems, to address the critical issue of vehicle fire safety. This discussion delves into the implications of the results, explores the system's strengths and limitations, and highlights areas for future development.

System Effectiveness and Reliability

The implemented system demonstrated a high degree of reliability in detecting vehicle fire hazards and accurately classifying fire severity. IoT-enabled sensors effectively captured critical environmental data, while preprocessing ensured that noisy or incomplete data did not interfere with the analysis. The machine learning models, specifically Linear Regression and Support Vector Machine (SVM), achieved impressive accuracies of 92.49% and 91.59%, respectively, confirming their ability to handle complex, real-world scenarios. The real-time integration with a mobile application and fire department dashboard further validated the system's operational effectiveness, enabling swift responses to emergencies.

Practical Implications

The practical applications of the system are vast. It addresses the growing need for improved vehicle safety measures in a world where automobiles are an indispensable part of daily life. Early fire detection and severity classification empower vehicle occupants and emergency responders with critical information to take timely action. This is especially relevant in modern vehicles with high-energy batteries and combustible materials, where the rapid escalation of fires poses significant challenges. Furthermore, the system's ability to minimize false alarms ensures trust and reliability, two factors essential for widespread adoption.

Strengths of the System

One of the key strengths of this system is its holistic approach to fire detection and response. By combining IoT sensors, machine learning algorithms, and user-centric interfaces, the system provides an end-to-end solution that enhances both safety and efficiency. The mobile application and dashboard offer intuitive, real-time access to critical data, ensuring that users and responders are well-equipped to handle emergencies. Additionally, the system's scalability and adaptability make it suitable for various vehicle types and operational environments, further broadening its applicability.

Challenges and Limitations

While the results are promising, the research revealed several challenges and limitations that must be addressed for broader implementation. One limitation is the dependency on sensor accuracy, as faulty or poorly calibrated sensors could lead to misclassification or missed detections. Environmental factors, such as extreme weather conditions or sensor exposure to dirt and debris, may also affect performance. Another challenge lies in the computational requirements of machine learning models, particularly when processing large datasets in real-time. Ensuring cost-effectiveness for large-scale deployment is another critical consideration, especially for older vehicles requiring aftermarket installations.

Comparison with Existing Systems

Compared to existing vehicle fire detection systems, this solution offers significant advancements in accuracy, functionality, and user experience. The inclusion of fire severity classification provides actionable insights that traditional systems often lack. Moreover, the seamless integration with emergency services ensures a coordinated response, reducing the time between detection and intervention. These features position this system as a superior alternative to conventional methods.

Future Directions

The research opens avenues for further exploration and development. One area of focus could be enhancing the machine learning models to improve accuracy and reduce computational overhead. Exploring more advanced algorithms, such as deep learning techniques, could offer additional benefits in identifying subtle patterns in sensor data. Expanding the dataset to include a wider variety of fire scenarios would also strengthen the system's generalizability. Furthermore, integrating additional sensors, such as cameras or infrared detectors, could provide richer data for more comprehensive fire detection. Collaboration with automotive manufacturers and policymakers could help standardize this system across vehicles, making it a mandatory safety feature.

Impact on Road Safety

The successful implementation of this system has the potential to significantly impact road safety by reducing fatalities, injuries, and property damage caused by vehicle fires. By providing early warnings and severity assessments, the system ensures timely interventions, preventing the escalation of fires. Its scalability and adaptability make it a valuable tool for individual vehicles, fleet operators, and emergency services alike. Additionally, the system's integration with mobile applications educates users about vehicle safety, fostering a culture of awareness and preparedness.

6.CONCLUTION

The research and development of the vehicle fire detection and severity assessment system represent a groundbreaking step toward enhancing road safety and addressing the overlooked issue of vehicle fires. By leveraging advanced technologies such as IoT, machine learning, and real-time communication systems, this project successfully demonstrated a holistic approach to fire detection, severity classification, and emergency response. The conclusions drawn from this study highlight the efficacy, reliability, and transformative potential of the proposed solution in minimizing the risks and impacts of vehicle fires.

System Effectiveness

The integration of IoT sensors, including temperature sensors, gas detectors, and GPS modules, forms the backbone of this system. These sensors provided continuous and accurate monitoring of the vehicle's environment, detecting abnormal conditions indicative of fire hazards. The data preprocessing process ensured that the raw sensor data was cleaned, normalized, and prepared for machine learning analysis. This step was critical in maintaining the reliability of the system and enhancing its ability to detect genuine fire incidents while minimizing false alarms.

The machine learning models used in this system—Linear Regression and Support Vector Machine (SVM)—delivered highly accurate results. Linear Regression achieved an overall accuracy of **92.49%**, excelling in predicting continuous fire severity levels and providing granular insights into fire intensity. SVM, with an accuracy of **91.59%**, proved highly effective in categorizing fire severity into discrete levels, such as low, medium, and high. These results underscore the robustness of the machine learning models and their ability to generalize across various fire scenarios and environmental conditions.

The mobile application and fire department dashboard added significant value to the system by ensuring real-time communication and accessibility. The mobile app provided vehicle occupants with instant alerts, including fire severity levels, GPS-based location details, and actionable recommendations. Simultaneously, the fire department dashboard displayed essential information, such as the incident's location, severity, and estimated response time, streamlining the coordination and prioritization of emergency resources. The seamless integration of these components proved vital in reducing response times and improving the effectiveness of emergency interventions.

Practical Implications

The practical implications of this research extend beyond individual vehicle safety. The system's ability to provide early detection and accurate severity assessments can transform how emergency services respond to vehicle fires. By equipping responders with critical information, the system enables better preparation, resource allocation, and overall safety for both emergency teams and vehicle occupants. The scalability of the system ensures that it can be deployed across diverse vehicle types and operating environments, making it a versatile solution for individual users, fleet operators, and automotive manufacturers.

Moreover, the system's ability to reduce false alarms addresses one of the most significant challenges in fire detection systems. By leveraging advanced preprocessing techniques and machine learning algorithms, the system ensures that alerts are only triggered during genuine fire events. This reliability fosters trust among users and emergency services, paving the way for widespread adoption.

Challenges and Limitations

Despite its success, the research identified some challenges and limitations that must be addressed for large-scale implementation. The system's performance depends heavily on the accuracy and durability of IoT sensors, which may be affected by environmental factors such as extreme weather or sensor degradation over time. Additionally, the computational requirements of machine learning models, particularly in real-time scenarios, could pose challenges for resource-constrained environments. Cost-effectiveness is another critical consideration, especially for aftermarket installations in older vehicles.

Future Scope

The findings of this research open the door to further advancements and refinements. Future work could focus on integrating more advanced machine learning models, such as deep learning algorithms, to improve accuracy and adaptability. Expanding the dataset to include a wider variety of fire scenarios and environmental conditions would further enhance the system's generalizability. Additionally, incorporating new sensor types, such as cameras or infrared detectors, could provide richer data for more comprehensive fire detection and classification.

The system also has the potential to be integrated with vehicle telematics and advanced driver-assistance systems (ADAS), creating a unified safety framework. Collaboration with automotive manufacturers, regulatory bodies, and emergency service providers could facilitate the standardization of this system, making it a mandatory feature in vehicles. Such initiatives would not only enhance vehicle safety but also promote innovation and growth in the automotive industry.

Impact on Society

The implementation of this system has the potential to significantly impact road safety and reduce the societal burden of vehicle fires. Early detection and timely intervention can save lives, minimize injuries, and reduce property damage, contributing to safer roads and communities. The system's scalability and adaptability make it a valuable tool for both developed and developing regions, addressing the global challenge of vehicle fire safety.

Moreover, the project demonstrates the power of integrating emerging technologies to solve real-world problems. By combining IoT, machine learning, and real-time communication, the system sets a new standard for innovation in vehicle safety. It serves as a model for how technology can be harnessed to address critical challenges and improve quality of life.

Final Thoughts

In conclusion, this research underscores the importance of proactive measures in addressing vehicle fire hazards. The proposed system represents a significant advancement in fire detection, severity assessment, and emergency response, offering a comprehensive and user-friendly solution. While challenges remain, the results of this study validate the feasibility and effectiveness of the system, paving the way for its adoption and further development.

By continuing to refine and expand this solution, it is possible to create a future where vehicle fires are detected and mitigated before they escalate into life-threatening incidents. The success of this project not only enhances vehicle safety but also demonstrates the transformative potential of technology in solving complex problems, making it a valuable contribution to the field of road safety and emergency response.

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