

Early Detection of Fire Accidents in Electric and CNG Vehicles Using a Battery and Gas Management System

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Abstract- In today's world, Electric Vehicles (EVs) and Compressed Natural Gas (CNG) vehicles have metamorphosed the automobile industry due to their eco-friendly nature and cost-effectiveness. However, one of the critical challenges faced by both EVs and CNG vehicles is the risk of fire accidents, primarily caused by thermal runaway, faulty Battery Management Systems (BMS), gas leaks, and overheating and improper venting mechanisms for cells to release heat. Over the years, many fire detection and fire handling techniques have been proposed and developed that consist of sensor values, temperature, voltage which focus mainly on battery health. This paper proposes an intelligent early fire detection system using an advanced BMS and Gas Management System (GMS) techniques and real-time sensor monitoring. The system utilizes various sensors such as temperature, flame, vibration, gas leakage, and voltage sensors to detect anomalies and predict potential fire hazards. The proposed system ensures real-time monitoring and early warning, thereby improving the safety and reliability of EVs and CNG vehicles.

I. INTRODUCTION

The increasing adoption of EVs and CNG vehicles has significantly impacted the transportation sector, offering benefits such as reduced greenhouse gas emissions and lower operational costs. EVs have become a major attraction in transportation environmentally friendly, and provide a comfortable travel experience. There are several factors driving the shift from traditional vehicles to EVs. Conventional vehicles rely on non-renewable energy sources like coal, petroleum, and natural gas, which negatively impact the environment and contribute to pollution, ultimately exacerbating global warming and the greenhouse effect, resulting in various health issues. Additionally, using EVs is more cost-effective compared to traditional vehicles that predominantly use petrol and diesel, which are quite expensive.

Despite these advantages, fire hazards remain a critical issue due to battery related failures in EVs and gas leaks in CNG vehicles. Thermal runaway, electrical

short circuits, gas leakage, poor ventilation, and improper charging or fueling mechanisms are the primary causes of fire incidents. A real-time, intelligent fire detection system is essential to prevent catastrophic accidents and ensure user safety.

Fire is a significant factor that hinders the widespread acceptance of electric vehicles and CNG vehicles. Fire incidents can lead to an irreplaceable loss of both life and property. Research by numerous scientists indicates that fires may become more prevalent in the summer due to battery overheating and while filling the gas in CNG tanks. The primary causes of fires in electric vehicles include electrical short circuits, and in CNG vehicles are gas leaks due to using old batteries operators and lids, insufficient maintenance, poor cell quality, faulty charging, and overheating. Thermal runaway is the main reason that both EVs and CNG vehicles are at risk of catching fire or exploding. This phenomenon occurs when one cell in a lithium-ion battery catches fire, subsequently igniting adjacent cells in EVs and in CNG it ignites the inner temperature of cylinder while filling the gas. In CNG pressure ratio is also one of the factors which is responsible for fire in CNG vehicles

II. PROBLEM STATEMENT

Existing EV and CNG vehicle models do not have an effective safety mechanism for early fire detection, which results in critical losses such as vehicle destruction and loss of human life. There is no real-time monitoring system in place, and therefore it becomes difficult to forecast and avoid fire threats. This research will work on designing a sophisticated BMS and GMS that incorporate real-time sensor inputs to improve vehicle safety.

III. PROPOSED METHODOLOGY

The system proposed includes several sensors like temperature, flame, vibration, and infrared. Of these, fire detection sensors are important for ongoing

monitoring and battery performance level and CNG pressure management. The Battery Management System (BMS) with high-end features assists in improving battery performance, with sensor data being incorporated into the BMS. The system also utilizes a machine learning process called Automatic Speech Recognition (ASR) to convert speech to text within the user interface. In the given system, the vehicle is energized using a type of lithium-ion battery called LiFePO₄. The vehicle utilizes the SW18020P Vibration Sensor for detecting the vibration of an engine and DS18B20 Temperature Sensor to observe the temperature of the CNG's cylinder tank and the vehicle itself.

3.1 Sensor-Based Data Gathering-The system designed utilizes various sensors to track key parameters:

A heat sensor identifies battery cells and gas components overheating through the monitoring of their temperature in real-time. This is how it operates:

1. Sensor Installation: The sensor is installed close to battery cells, gas containers, or other key components that are prone to overheating.
2. Detection Mechanism: The sensor detects temperature variation and transmits this information to the control system of the vehicle. If temperature rises above a safe level, it suggests overheating.
3. Alert and Response: Once overheating is detected, the system initiates an alert so that intervention at the right time, like cooling or shutdown, can be undertaken to avoid damage or fire.

A flame sensor would detect flames or unusual heat in key vehicle parts to detect possible fire threats. This is how it functions:

1. Sensor Position: The flame sensor is usually positioned where fires are most likely to occur, i.e., close to the engine, exhaust, or fuel system.
2. Detection Mechanism: The sensor detects infrared (IR) radiation or ultraviolet (UV) light emitted by flames. It is sensitive to specific wavelengths that are characteristic of fire.
3. Signal Processing: When the sensor detects a flame or high heat, it sends a signal to the vehicle's control system.

4. Early Warning: If a possible fire is detected, the system sends an alarm to the driver or automatically activates fire suppression systems if equipped, avoiding further damage.

A vibration sensor to monitor engine vibration for fault detection at an early stage operates by detecting the frequency and amplitude of vibrations emitted by the engine. It works as follows:

Working Principle:

1. Sensor Placement: The vibration sensor is normally attached or located near important engine parts, including bearings, shafts, or the engine block. The aim here is to sense abnormal vibrations that could signify issues.
2. Detection Mechanism: The sensor captures mechanical vibrations that take place inside the engine. Vibration is usually caused by an unevenness of rotating parts, misalignment, wear and tear, or system imbalances. The sensor captures these oscillations and converts them into electrical signals.
3. Signal Processing: The output from the sensor typically goes to a signal processor or monitoring system that examines the vibration's frequency, amplitude, and pattern. These parameters are significant because distinct faults in an engine generate specific vibration characteristics.
4. Threshold Setting: The system is tuned with known vibration patterns of a healthy engine. When the vibration levels go beyond the normal threshold, it could be an indication of a fault like misalignment, imbalance, wear on bearings, or other mechanical faults.
5. Early Fault Detection: With real-time monitoring of the vibration levels, the system can detect abnormal patterns before they cause major damage. For instance:
 - Excessive vibration might suggest issues like misalignment or bearing wear.
 - Unexpected frequency shifts could point to issues such as a cracked component.
6. Alerts and Maintenance: Once abnormal vibrations are detected, an alert is sent to maintenance personnel or the control system. This makes for early diagnosis and timely repair, reducing the chances of complete

breakage, saving expensive repairs, and extending the working life of the engine.

A voltage sensor in electric vehicles (EVs) monitors the battery voltage to prevent overcharging or over-discharging, keeping the battery in the healthiest possible condition. This is how it works:

1. Sensor Installation: It is coupled to the battery system and tends to monitor the voltage levels of the cells or total battery pack.

2. Detection Mechanism: It continuously measures the voltage of the battery, comparing it with safe operating limits. When the voltage becomes excessively high (overcharging) or excessively low (over-discharging), it indicates a potential problem.

3. Control System: The sensor provides voltage information to the control system of the vehicle, which can take remedial action in the form of charging curtailment, battery disconnect, or controlling energy flow to avoid damage.

4. Prevention: By monitoring voltage variation, the sensor avoids letting the battery run outside its safe operating range, thus preventing performance loss, battery life reduction, or even safety risk in the form of thermal runaway.

Gas leak sensor senses leakages in compressed natural gas fuel tanks and pipeline to avoid gas explosions by observing the availability of gas. Its operation is explained below

1. Sensor Placement: A sensor is positioned close to compressed natural gas fuel tanks, pipes, and similar vital places where a leakage can happen easily.

2. Detection Mechanism: The sensor is responsive to certain gas molecules (such as methane) present in the air. It monitors gas concentration and relates it to safe threshold levels.

3. Alert System: When a gas leak is sensed, the sensor alerts the control system of the vehicle or the driver, warning them of the danger.

4. Preventive Actions: When a leak is detected, the system may take measures like cutting off the fuel supply, activating ventilation systems, or initiating an emergency shutdown to avoid hazardous conditions such as explosions.

A thermal and gas management system in cars, including electric cars (EVs) and CNG-fueled cars, is essential for ensuring peak performance and safety through temperature management and gas leak detection. Here's how it works:

For Electric Vehicles (EVs):

1. Battery Temperature Regulation:

- The system applies cooling systems such as heat sinks, liquid cooling, and fans to control the temperature of the battery.
- Such mechanisms do not let the battery get overheated when charging as well as while discharging to remain within its safe operating regime.

2. Cooling Process:

- Liquid coolant circulates through cooling plates or channels in the battery pack, absorbing excess heat and dissipating it through a radiator or heat exchangers.
- Fans and heat sink further assist in cooling the system by promoting airflow and heat dissipation.

3. Prevents Overheating:

- The system automatically notifies emergency responders of critical situations, such as fire hazards or excessive gas leaks, along with the location of the vehicle. Even if the driver is unable to respond quickly, this guarantees prompt intervention.
- Overheating can reduce performance, shorten battery life, and, in severe cases, cause thermal runaway or fires. By regulating ideal temperatures, the thermal management system prevents these issues.

For CNG Vehicles:

1. Gas Leak Detection:

- The system incorporates gas sensors to monitor the concentration of CNG in the vehicle's fuel system, including tanks and pipelines.
- The system automatically notifies emergency responders of critical situations, such as fire hazards or excessive gas leaks, along with the location of the vehicle. Even if the driver is unable

to respond quickly, this guarantees prompt intervention.

- If a leak is detected, the system will notify the driver and take appropriate action, such as turning off the fuel supply or starting the ventilation.

2. Ventilation:

- Proper ventilation in CNG cars is necessary to avoid gas buildup, which may result in fatal explosions.
- The design provides sufficient ventilation in the fuel compartment and other essential areas such that any seepage gas can safely vent.

Key Benefits:

- **Safety:** Through prevention of EV battery overheating and gas leak detection for CNG vehicles, the system greatly enhances overall vehicle safety.
- **Efficiency:** The heat management system ensures EV operation at peak efficiency by keeping battery temperature at optimal levels, and this enhances the performance and life of batteries.
- **Prevention of Explosion and Fire:** The system precludes explosion and fire by detecting and managing leakage of gas in CNG cars.

Key Features of OBD Integration:

1. Real-Time Diagnostics:

- OBD technology continuously monitors and analyzes various vehicle systems, including the battery, engine, gas system, and safety components.
- It tracks important parameters like battery health, engine temperature, gas leakage levels, and fire risk levels.

2. User-Friendly Interface:

- The OBD system offers an easy-to-use interface that presents these important data points on a dashboard or through an app.
- The dashboard displays the battery's health condition, temperature levels, and gas level to inform the driver about the vehicle's status.

3. Alerts and Notifications:

- Once any parameters exceed the safe limits (e.g., battery overheat, leakage of gas, or fire danger), the system provides real-time alerts to the driver.
- The driver is notified to perform an urgent operation, for instance, bringing the vehicle to a halt, applying cooling systems, or handling other problems.

4. Emergency Notifications:

- Whenever critical conditions like fire risks or high gas leakages are sensed, the system automatically sends alerts to emergency personnel along with the vehicle location.
- This ensures timely intervention, even if the driver cannot react promptly.

IV. RESULTS AND DISCUSSION

By combining state-of-the-art battery management systems (BMS) and gas management systems (GMS) with real-time sensor input and machine learning (ML) techniques, the early fire detection system proposed in this study has enormous potential to increase the safety of compressed natural gas (CNG) and electric vehicles (EVs). In order to promptly notify the driver and emergency services of fire danger, the system tracks key vehicle parameters in real-time. The study's findings and conclusions are as follows:

Monitoring in real time: Real-time monitoring of critical vehicle parameters was made possible by the use of multiple sensors, including temperature, vibration, flame, gas leak, and voltage sensors. The following could be observed by the system:

Battery cell temperatures for potential overheating, which is one of the main causes of EV fire incidents and thermal runaway.

Levels of gas leakage in CNG tanks, in order to promptly detect any gas leaks that might cause an explosion or fire.

Engine vibration levels, which assisted in identifying possible mechanical problems like wear and tear or misalignment that could pose a fire hazard.

Voltage levels are crucial for maintaining battery safety and avoiding overheating because they stop the battery from being overcharged or undercharged.

To enable the system to respond to the presence of flames at an early stage, flame detection is used to detect potential fire hazards in a timely manner.

Early Anomaly Detection: By identifying abnormalities a few steps ahead of time, the system was able to provide an early warning of potential fire hazards.

There was evidence of heating in gas units or battery cells, which, if left unchecked, could cause thermal runaway and fire hazards.

Early detection of gas leaks in CNG-powered cars also decreased the possibility of an explosion or fire due to hidden leaks.

Unusual engine vibrations were shown to be an indicator of impending mechanical failure in the form of misalignment or unbalanced components, which would result in fire hazards if left unaddressed.

Notification and Alerts: The system effectively delivered notifications and alerts to both the driver and emergency responders in dangerous conditions:

The system warned the driver of problems like excessive gas leakage levels or the existence of fire hazards, allowing the driver to react promptly and prevent possible accidents.

Automatic safety features were activated when hazardous conditions were sensed. For example, cooling systems were engaged to avoid battery overheating, and the fuel supply was cut off in the event of sensed gas leaks.

Emergency services were alerted in real time, being informed of the precise location of the vehicle and the type of emergency, which greatly enhanced the likelihood of prompt intervention.

Thermal and Gas Management: The system ensured efficient temperature management and gas regulation, avoiding scenarios that may precipitate fires or explosions:

Thermal management for EVs ensures battery temperature management through liquid cooling, heat sinks, and fans. This enabled optimal battery temperature, avoided battery overheating, and minimized thermal runaway risks.

The gas management system in CNG vehicles guaranteed adequate monitoring of gas pressures and leak levels. The system also featured ventilation means that did not allow the build-up of gas within closed spaces, which otherwise would result in hazardous explosions or fires.

OBD Integration: The addition of On-Board Diagnostics (OBD) improved the system's capability to offer real-time diagnostics and essential information to the driver and emergency personnel:

The OBD system offered the driver an easy-to-understand display of important information, such as the health of the battery, engine temperature, gas leakage status, and fire hazards, allowing the driver to decide and respond immediately if necessary.

In the event of extreme conditions, emergency personnel were automatically alerted, provided with the vehicle's precise location and important information regarding the emergency. This feature is crucial in ensuring prompt and efficient responses, especially when the driver can be incapacitated or is unable to respond promptly.

Overall, the system proved to be an extremely effective method of improving vehicle safety through the incorporation of real-time monitoring, early warning, and timely notification. The system eliminated the primary fire risks in EVs and CNG vehicles of battery overheating, gas leak, and mechanical faults, thus minimizing the chances of fire accidents.

V. DISCUSSION

The proposed early detection system in this research is responsible for fire accidents in electric vehicles (EVs) and CNG vehicles by providing early warnings prior to disastrous incidents. Early action is critical in reducing the risk associated with fire hazards, particularly in such vehicles, where safety from fire is a top issue. Through the issuance of real-time alerts, the system guarantees that the drivers are in a position to act instantly and safeguard themselves as well as the vehicle, averting possible damage, occupants' safety, and in certain instances, loss of life. With the growing use of EVs and CNG vehicles, having an efficient early detection system is paramount in the promotion of road security as well as the mitigation of fire-caused accidents.

The intricacies of fire dangers in EVs and CNG vehicles emphasize that a reliable fire detection system should be implemented. For EVs, fire often results from thermal runaway, electrical malfunction, and overheating of vital components like the battery. These can pose catastrophic outcomes when not detected immediately. Conversely, CNG cars are exposed to fire hazards by gas leakage and faulty fueling or venting systems. Both of these have been addressed through the suggested system, which checks important parameters including temperature, voltage, gas concentrations, and vibrations of the engine continuously. Detection of early indication of failure or malfunction by the system enables alerting of the driver to any impending fire danger, thus timely intervention before an actual fire disaster occurs.

Though the system was performing well, plenty of room remains for additional study and development. For instance, subsequent work could involve enhancing machine learning algorithms operating within the system, especially for use in fluctuating environments in which sensor outputs change. Such advancements would increase the accuracy with which the system can predict potential fire threats and make the system more reliable for use in everyday applications. Also, with changing battery safety regulations for EVs, future research could focus on the maximization of battery cooling systems and fire suppression measures. These modifications could increase the system's efficacy in eliminating the risk of fires in EVs. Likewise, gas leak monitoring in CNG vehicles can be made more efficient to identify very small leaks so that vehicle safety can be better controlled and nothing is left at risk.

The scalability of the system proposed is another significant benefit. Different manufacturers and models can use it because it can be applied to a wide range of EVs and CNG vehicles. Additionally, the system can be incorporated into the infrastructure of smart cities, which would improve coordination with emergency response units. With the potential for even greater public safety and faster emergency response times, this integration would greatly improve the entire transport safety network. The system can become an essential part of contemporary transportation by growing in scope and potential, which would increase the security of both vehicles and their contents.

VII. CONCLUSION

A Battery Management System (BMS), Gas Management System (GMS), and real-time sensor monitoring with machine learning (ML) comprise the research's envisioned smart early fire detection system, which is thought to be a very effective way to improve the dependability and safety of compressed natural gas (CNG) and electric vehicles (EVs). Particularly in EVs and CNG cars, where the risk factors are different but no less dangerous, vehicle fire accidents can be very damaging. This system improves overall vehicle safety by resolving significant problems that can result in catastrophic fire accidents, such as thermal runaway, gas leakage, and engine malfunction. Thermal runaway, a situation in which the battery's cells overheat and a series of events follows, is one of the main issues with EVs.

The primary risk of fire or explosion in CNG vehicles is gas leakage, which must be identified quickly. The system uses a network of sensors to continuously monitor many important parameters, such as vibration sensors to check the engine's mechanical condition, gas sensors to detect leaks in CNG vehicles, and temperature sensors to monitor the temperature of EV battery cells. By doing this, it detects any early indicators of mechanical failure, gas leak, or overheating, enabling the system to send out early alerts and stop fire before it starts. This task is performed by the Battery Management System (BMS), which also controls the battery's temperature to prevent overheating.

Thermal runaway is typically preceded by overheating, which the BMS reduces by keeping the batteries at ideal temperatures. In CNG vehicles, the Gas Management System is also intended to track gas pressures, identify leaks, and regulate the gas's-controlled release. This will be essential to preventing gas buildups, which can result in catastrophic events like fire or explosion.

Furthermore, by giving the driver real-time feedback, the integration of on-board diagnostics (OBD) with the initial fire detection system greatly improves the user experience. The OBD system provides the driver with feedback on the state of their car while continuously checking the condition of vital parts like the engine, battery, and gas system. The driver's comments regarding the state of their car. The system warns the driver when it detects problems like overheating, gas

leaks, or engine failure so they can take preventative action before a dangerous situation occurs. By providing early intervention features, the OBD system not only offers real-time diagnosis but also generally improves the car's safety and dependability. In conclusion, the smart early fire detection system offers a novel way to reduce the risk of fire in EVs and CNG cars. The system guarantees improved vehicle safety and dependability by thwarting the unique threats posed by thermal runaway, gas leakage, and mechanical breakdown. The system provides advance warnings and diagnostics by integrating OBD systems with machine learning, enabling drivers to efficiently take care of their cars. All in all, the technology is revolutionary.

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