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Development of Smart Safety System for Electric Vehicles

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Abstract: Electric Vehicles (EVs) are increasingly adopted as a sustainable alternative to conventional fuel-based transportation due to their environmental benefits and energy efficiency. However, battery-related safety issues such as overheating, short circuits, and thermal runaway pose serious risks, often leading to fire hazards. This project presents the development of a Real-Time Monitoring and Safety Protection System for Electric Vehicles designed to enhance battery safety and prevent fire incidents. The proposed system integrates sensors to continuously monitor critical parameters such as battery temperature, voltage, and current. These parameters are processed using a microcontroller and displayed on an LCD screen to provide real-time information to the driver. When abnormal conditions such as excessive temperature or electrical fluctuations are detected, an automatic power cutoff mechanism is triggered to disconnect the power supply and prevent further damage. Additionally, a buzzer alert system provides immediate warning to occupants, ensuring timely action. The system offers a cost-effective, reliable, and proactive safety solution that focuses on early detection and prevention rather than reactive fire suppression. This approach improves EV reliability, protects passengers, and contributes to safer electric transportation systems.

Keywords: Fire Situation, Controller, Emergency Alert, Accident Prevention, Real-Time Monitoring etc.

I. INTRODUCTION

In our country fire accident is a very common phenomenon. Many wealth and lives are fallen in danger. As a developing country we have no modern technology to solve this problem. The main sector of fire brigade has limitation to overcome it. Sometimes police, military come to the firing spot to help them. But this is not enough. Electric vehicle batteries bring new safety challenges to the vehicle development process, and rigorous testing must be carried out to ensure the minimal risk of fire. Research has shown that electrical system failures are among the top 4 causes of automobile related fires.

Fig.1 Electric Vheciles fire situation

Many people have the notion that only all-electric and hybrid vehicle battery packs are problematic and can start a fire. It is a significant challenge for the automotive industry to tackle, but car fires are not a new problem; around 900 car fires are said to occur on Indian roads for every billion miles travelled. If an Automatic fire extinguishing system is available, it will offer greater flexibility. Several gas jetting nozzles are arranged at desired locations within a region. The gas jetting nozzles are connected through a valve and a pipe to the extinguishers.

The fire sensors are arranged at desired locations within the region. In response to a fire signal from the fire sensors, the valve is opened to cause fire-extinguishing gas to jet from the gas jetting nozzles into the region so that automatic fire extinguishing can be achieved therein.

Nowadays, domestic and industrial fire accidents are getting frequent. It increases the amount of damage caused by fire and also the risk to human lives. A smart home automation system could be an easy solution to prevent small scale fire accidents from occurring in a home or to extinguish such fire hazard. But once it is spread out to the entire complex, the supporting factors for the fire cannot be controlled by the smart home automation system since the system is designed to control the fire only to that particular home. So, it won't control the fire on the entire building. Under such a situation, a fire extinguishing vehicle is necessary to control the fire throughout the entire complex. These needs paved the path to this research work.

The proposed system aims at building a guided vehicle that can be installed in a domestic or industrial environment, to alert the user in case of fire accidents. This vehicle can be guided by the user through mobile phone control to the intended location where the fire accident is occurring and water can be sprayed to extinguish the fire via mobile phone control. The velocity, volume and the direction of water while spraying can also be controlled by the user. The developed vehicle can be observed in the screen of the mobile phone from far away to guide the motion of the vehicle and thereby the user can communicate with it to effectively extinguish the fire. IoT (Internet of Things) integration enables the guided vehicle to organise, analyse and process data, allowing the user to make optimum decisions on a real-time basis.

By this way, the damage that can be caused by fire before the arrival of the fire extinguishing squad can be drastically reduced and the risk of involvement of fire extinguishing squad can also be minimised. The chance of life loss and / or injury in a normal automobile fire accident can be reduced by automatic door unlocking system [4]. But fire extinguishing squads are the people who are dedicated to stopping the fire even at the expense of their lives. So, this research work targets to minimise human involvement to stop any fire accidents.

II. PROBLEM IDENTIFICATION

1) Research has shown that electrical system failures are among the top 4 causes of automobile related fires. Many people have the notion that only all-electric and hybrid vehicle battery packs are problematic and can start a fire.
2) A Few years back, a Tesla Model S, which was awarded the title of the safest car in the world by the media, caught fire in late 2013.
3) The concerns and risks associated with electric or hybrid cars go way back. There are even more risks with every new design or model that comes out. It may take a while for these high profiled incidents to ebb away from the mind of a lot of people

The common factors that lead to car fire in electric vehicles are given below-

a) Battery Overcharging

Every system has a limit of sustaining high loads on it and so the EV battery too. The electric vehicle battery also has some limit of electricity provided to it. This limit is stated by the manufacturer. If this limit is crossed, then some malfunctioning, damage to electrical system or in some cases the vehicle can also catch fire. This happens when excess of electric current flows though the battery.

Due to this excessive current the battery gets heated and it catches fire. This occurs normally when the owner or driver keeps the battery for charging overnight and forgets to remove it from charging.

b) Battery Electrolyte Leakage

The Lithium-ion battery also presents a risk of degradation by a violent and dangerous combustion reaction. This combustion can occur spontaneously as soon as the batteries intern temperature reaches 65 °C and is very likely to occur above 75 °C.

In case of burning of the battery, hydrofluoric acid is produced and released by thermal decomposition of the PF_6^- ions of the electrolyte contained inside the battery.

Concentration of released hydrofluoric acid is variable and depends on the quantity of electrolyte burnt in the combustion process and the combustion temperature. Other toxic gases are also produced and released during the electrolyte combustion (carbon oxides from combustion of ethylene and propylene carbonates). To prevent leaking or burning of the battery, very cautious manipulation of Li-ion batteries is recommended.

c) Short circuit in Electric Components

Short circuits occur due to overloading or when two bare wires touch. A circuit is said to be overloaded when too much current flows causing heat build up or wiring to break down. This can lead to sparks and fire. A short circuit is an electrical circuit that allows current to travel along an unintended path. Short circuits cause fire, especially when the positive wires get in contact with the flame; a spark is formed leading to fire. When the wires join together, a spark can be formed causing a blaze.

d) Road Crash

Normally, a car isn't supposed to catch fire after a collision. But in an electric vehicle, the battery is the main reason for fires. The batteries in electric cars behave like any other battery, it ignites when punctured. So, if for example, an electric car travelling at top speed hit a small object or debris that punctures its battery, it would ignite. There are some cases that states how dangerous is this battery issue.

The Chevy Volt made headline in late 2011 and early 2012 when a couple of cars caught fire during impact testing. After a thorough investigation into the incidence, federal regulators determined that the fire may have been caused by the interaction between leaking coolant with damaged batteries during the test.

Figure 2: EV Busses caught fire and totally buried.

III. LITERATURE REVIEWS

A. Literature Survey

The movement of the vehicle is dictated by the combination of sensor-based inputs and user guidance. When the fire is detected by the fire detection sensor, the signal is immediately passed to the controller. IOT modules will be activated alerting the user about the fire accident. Once the alert is received, the user can guide the vehicle to the required location with the help of Blynk software & in-built camera module to extinguish the fire. The servo motor connected with the firefighting hose can Control the direction and volume of water to be sprayed. The controls of the servo motors are with the user. The proposed firefighting vehicle is designed to function using Internet of Things (IoT), thereby enabling the user to control the fire from anywhere.

1) Zhang et al. (2021), A battery management system was proposed for an electric vehicle, incorporating voltage and current sensors, along with a temperature sensor and a microcontroller for data acquisition and analysis. This system aimed to monitor the state of charge and temperature of the battery, activating a cooling system when the battery temperature surpassed a safe threshold. The research concluded that the implemented system effectively regulated the battery temperature, thereby enhancing the overall battery performance.
2) Liu et al. (2020), A battery management system tailored for electric vehicles was proposed, integrating an Arduino microcontroller, voltage, and current sensors, along with a wireless communication module for data transmission. The system's primary objective was to monitor the battery's state of charge, health, and temperature, while also providing real-time data to drivers or fleet operators through a mobile application. The research concluded that the implemented system significantly enhanced battery efficiency and safety, while also offering valuable insights for vehicle operators.
3) Saha et al. (2020), The development of a battery management system for an electric rickshaw was explored, incorporating voltage and current sensors, a microcontroller, and a temperature sensor. The primary purpose of this system was to monitor the battery's state of charge, temperature, and health, and to trigger a cooling system if the battery temperature surpassed a safe limit. The research concluded that the implemented system significantly enhanced the battery's overall performance and reliability.

4) Ghaffari et al. (2019), A battery management system for an electric vehicle was proposed, integrating a current sensor, voltage sensor, temperature sensor, and microcontroller for data acquisition and analysis. The system aimed to monitor the battery's state of charge, temperature, and health, and to trigger a cooling system if the battery temperature surpassed a safe threshold. The research concluded that the implemented system effectively improved the battery's overall performance and safety while extending its lifespan.
5) Khan et al. (2019), A battery management system was suggested for electric vehicles, employing a microcontroller, voltage and current sensors, and a GSM module for data transmission. The system's purpose was to oversee the battery's state of charge, health, and temperature, and to deliver real-time data and alerts to vehicle operators or fleet managers through SMS. The research determined that the proposed system significantly enhanced battery efficiency and reliability, offering valuable insights for vehicle operators.
6) Kasmi et al. (2019), A battery management system was proposed for electric vehicles, utilizing a current sensor, voltage sensor, and a microcontroller for data acquisition and analysis. The system's objective was to monitor the battery's state of charge, health, and temperature, while also triggering a cooling system if the battery temperature surpassed a safe threshold. The research concluded that the proposed system effectively regulated battery temperature and prolonged battery lifespan.

B. Literature Summary

The reviewed literature emphasizes the importance of real-time monitoring and automated protection in electric vehicle battery systems. Researchers have proposed IoT-enabled frameworks for continuous temperature and voltage monitoring, improving early fault detection. Several studies introduced embedded fire detection systems using smoke and flame sensors to reduce response time. Intelligent cooling mechanisms, including high-speed fans and liquid cooling, were shown to effectively control battery overheating. Cloud-based platforms enable remote monitoring and predictive maintenance for fleet management. However, most systems focus on specific aspects such as detection, cooling, or analytics separately. Overall, the literature confirms that integrating IoT, embedded controllers, and automated suppression mechanisms significantly enhances EV safety and reliability.

C. Research Gap

Although recent studies have explored IoT-based battery monitoring, thermal runaway detection, and automated cooling systems, there remains a significant gap in developing an integrated, cost-effective, and compact safety protection framework for electric vehicles. Most existing research focuses on either detection or suppression independently, rather than combining real-time monitoring, automated response, and remote IoT communication in a single unified system. Limited attention has been given to low-cost microcontroller-based implementations suitable for small and medium EVs. Additionally, scalability, reliability under dynamic driving conditions, and real-time decision-making accuracy require further improvement. Therefore, there is a need for a comprehensive, automated, and economically feasible safety system that ensures early detection, instant response, and remote monitoring.

IV. METHODOLOGY

A. Proposed System

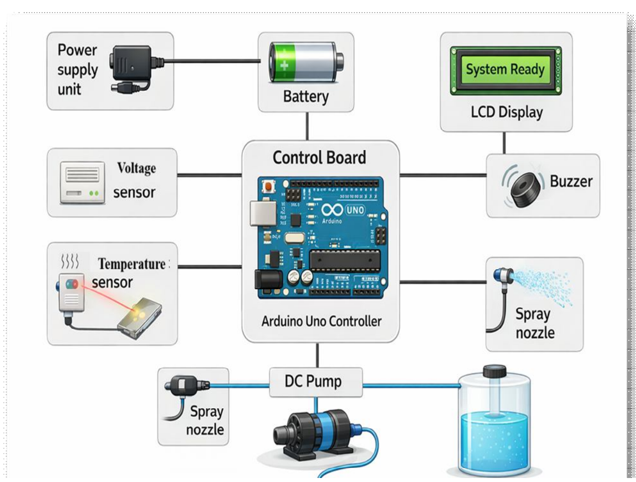

Figure 3. Proposed System

B. Working Principle

The system is designed to monitor and manage the temperature of the battery inside an Electric Vehicle (EV) to prevent overheating and potential damage. It uses a combination of sensors, a microcontroller, and cooling mechanisms for efficient operation.

When the battery temperature rises, sensors such as a smoke sensor, photoelectric sensor, and temperature sensor detect the situation. The smoke sensor and photoelectric sensor monitor the presence of smoke, while the temperature sensor continuously measures the thermal condition of the battery. If any abnormalities are detected, the sensors send their readings to the Arduino microcontroller for processing.

The microcontroller, programmed with specific logic, evaluates the data received from the sensors and determines the appropriate response. If smoke or signs of overheating are detected by the smoke or photoelectric sensor, the microcontroller activates a buzzer to alert nearby users and displays warning messages on the LCD screen for immediate attention.

In cases where the temperature sensor indicates overheating, the microcontroller also activates a high-speed DC fan along with the buzzer and LCD display. The DC fan operates at high speed to increase airflow around the battery, helping to dissipate heat and reduce the temperature to safe levels.

This system provides continuous monitoring and a quick response to battery overheating conditions, improving the safety and protection of the EV battery system.

C. Main Features

1) Real-Time Battery Monitoring: Continuously monitors critical battery parameters such as temperature and fire presence to ensure safe operation.
2) Early Hazard Detection: Detects abnormal conditions like overheating, smoke, or flame at an early stage to prevent thermal runaway.
3) Automatic Safety Activation: Instantly activates high-speed DC fan, buzzer, and other protective mechanisms when unsafe conditions are detected.
4) Microcontroller-Based Control: Uses Arduino Uno (ATmega328P) for fast data processing and intelligent decision-making.
5) Visual Status Display: LCD screen provides live temperature readings and alert messages for user awareness
6) Audible Warning System: Buzzer generates immediate sound alerts during emergency situations.
7) Relay-Controlled Isolation: Ensures safe switching between low-power control circuits and high-power devices
8) Cost-Effective Design: Utilizes affordable components for practical and scalable implementation.
9) Compact and Integrated System: Designed for easy installation inside EV battery compartments without major modifications.

D. Hardware Used

1) Arduino Uno (ATmega328P): Central microcontroller for processing sensor data and controlling output devices.
2) Temperature Sensor (LM35): Monitors real-time battery temperature to detect overheating conditions.
3) Fire/Flame Sensor: Detects smoke or flame presence near the battery pack for early fire identification.
4) Relay Module: Acts as an electronic switch to control high-power devices like fans and sprinklers.
5) High-Speed DC Fan: Provides rapid cooling to prevent thermal runaway during high-temperature conditions.
6) Buzzer: Generates audible alerts during abnormal or emergency situations.
7) 16x2 LCD Display: Displays temperature readings and system status messages for driver awareness.
8) Rechargeable Battery & Power Supply Unit: Provides regulated and uninterrupted power to the system components.

E. Software Used

1) Arduino IDE: For programming microcontroller functions and interfacing sensors.
2) Embedded C: Used as the primary coding language for hardware control.

V. RESULTS AND DISCUSSION

The proposed Smart Fire Safety System for Electric Vehicles (EVs) was successfully implemented as a working prototype using an electronic monitoring framework. The system was integrated with temperature, smoke, and photoelectric sensors, an Arduino microcontroller, a high-speed DC fan, a buzzer, and an LCD display to perform real-time monitoring and autonomous response to thermal hazards. The prototype was modeled on a miniature electric bus using plastic and metal sheets to simulate realistic conditions.

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The smart fire safety system for Electric Vehicles (EVs) was successfully implemented on a small-scale bus prototype constructed from sheet materials. The system was tested under various controlled environmental conditions to evaluate its real-time detection, notification, and response performance using temperature, smoke, and photoelectric sensors.
During the testing phase, simulated heat and smoke conditions were created to assess the responsiveness of the system. When the temperature exceeded 45°C, the DC cooling fan was automatically triggered to reduce the temperature. At the same time, the buzzer alarm was activated and the warning message was displayed on the LCD screen to alert users. Similarly, when the smoke concentration crossed 250 ppm, the smoke sensor and photoelectric sensor detected the abnormal condition and immediately activated the warning system. This early detection and automatic response mechanism helps in reducing the risk of fire hazards in electric vehicles and enhances passenger safety.

Table 1: Sensor Reading vs. System Response

Time (s)	Temperature (°C)	Smoke Level (ppm)	Photoelectric Intensity (lux)	Buzzer	DC Fan
0	32	80	250	OFF	OFF
10	38	120	270	OFF	OFF
20	45	200	300	ON	ON
30	47	260	320	ON	ON
40	41	150	280	OFF	ON
50	35	100	260	OFF	OFF

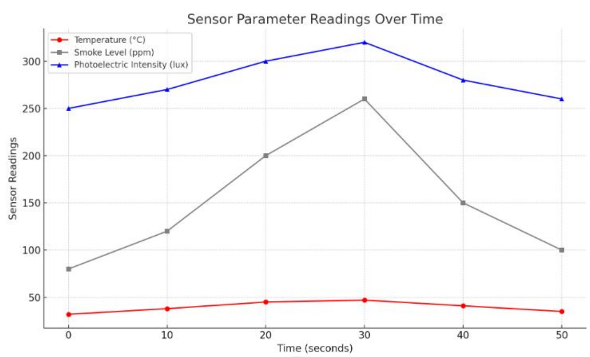

Figure 4. The graph displaying the sensor readings (temperature, smoke level, and photoelectric intensity) over time

The graph displays the sensor readings—temperature, smoke level, and photoelectric intensity—over time. It clearly shows how the system detects abnormalities around the 20–30 second mark and helps visualize the conditions that trigger the safety mechanisms.
This system has been developed for fire safety and monitoring, particularly in AC buses and electric vehicles. The proposed system mainly focuses on reducing human casualties and property loss during fire-related accidents. In this system, preventive measures are implemented automatically; therefore, the response time is very short and the potential damage can be minimized. The system is proposed as a safety enhancement for public transportation. Many accidents occur during night-time operations, and in situations where the driver is drowsy or inattentive, the alert mechanism in the form of a buzzer can provide immediate warning to the driver.
During testing, the system was able to accurately detect increases in temperature and the presence of smoke in the battery compartment. When the temperature exceeded a pre-set threshold (for example, 45°C), the temperature sensor transmitted the signal to the Arduino controller, which activated the DC fan to operate at high speed. At the same time, the buzzer alarm was triggered to alert nearby users.
The graphical output illustrates real-time sensor readings such as temperature, smoke concentration, and surrounding heat levels. These readings were plotted over time, demonstrating the sensor's rapid response to changes in environmental conditions. The system was able to detect and respond to hazardous conditions within seconds, significantly reducing reaction time compared to manual safety systems.

Additionally, the photoelectric and smoke sensors effectively detected combustion particles even in low-visibility conditions. The LCD display continuously updated the user with the current sensor readings and warning messages, making the system interactive and easy to monitor.

An important observation was the system's potential application in public transportation buses, especially AC buses where overheating may occur in enclosed compartments. Night-time safety is also improved through the buzzer alert mechanism, which can help alert a drowsy driver and prevent possible accidents.

From a cost and implementation perspective, the system is affordable, compact, and requires minimal maintenance, making it suitable for installation in various electric vehicle models. With further research and development, additional features such as driver monitoring systems, predictive safety analysis, and automatic fire suppression mechanisms could further enhance the overall safety system.

Overall, the smart fire safety system demonstrated high responsiveness, operational simplicity, and strong applicability in real-world electric vehicle environments, particularly in preventing overheating incidents and minimizing human and property loss during fire-related emergencies.

VI. ADVANTAGES AND APPLICATIONS

A. Advantages

1) Real-time Monitoring: Continuous monitoring of battery temperature ensures proactive detection of overheating issues.
2) Enhanced Safety: Prevents potential hazards like thermal runaway, fire, or explosion in EV batteries.
3) Efficient Cooling: High-speed DC fans effectively dissipate heat, maintaining battery health and extending its lifespan.
4) User-Friendly: The LCD display provides clear information about the system's status, making it accessible to all users.
5) Cost-Effective: Prevents costly damage to the EV by ensuring timely interventions.
6) Low Maintenance: The system is robust, requiring minimal maintenance over time.

B. Applications

1) Electric Vehicles: Battery temperature management in EVs to ensure safety and performance.
2) Renewable Energy Systems: Cooling batteries in solar or wind energy storage setups.
3) Data Centers: Managing heat in battery backups for uninterrupted operations.
4) Portable Electronics: Thermal regulation in high-capacity battery-powered devices.
5) Industrial Systems: Monitoring and cooling batteries in automated machinery or robotics.
6) Aerospace: Ensuring safe battery operations in drones, aircraft, and space applications.

VII. CONCLUSIONS

The integration of a Smart Safety System for Electric Vehicles (EVs) is crucial for enhancing the safety, performance, and longevity of EV batteries. This innovative system monitors key battery parameters such as temperature and smoke, providing real-time alerts to prevent hazardous conditions. In case of overheating or potential fire hazards, the system automatically activates safety mechanisms such as high-speed cooling fans or extinguishing units, effectively reducing the risk of accidents.

The system is designed to be simple and reliable, ensuring minimal maintenance and making it a practical and cost-effective solution. Its compact structure allows easy installation in electric vehicles without causing discomfort to drivers or passengers. Continuous monitoring of battery conditions enables quick detection of abnormal situations and immediate activation of protective mechanisms.

With further research and development, this smart safety system has the potential to significantly improve the safety standards of electric vehicles. It can be adapted for different battery types and configurations, making it suitable for a wide range of EV applications. Overall, the system contributes to improving the reliability, safety, and user confidence in modern electric transportation.

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