Design and Development of an Automatic Fire Extinguisher System for Motorsports Vehicles Using Smoke and Overheat Temperature Detection

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Abstract- Motorsports vehicles operate under extreme conditions, where high temperatures and the risk of fire pose significant safety concerns. This paper presents the design and development of an automatic fire extinguisher system integrated into a motorsports vehicle to enhance driver safety during fire-related emergencies. The system is built around an Arduino Uno microcontroller, interfaced with multiple sensors including the MQ-135 gas sensor for smoke detection, a temperature sensor, and humidity sensor to monitor the cabin environment. These sensors continuously collect real-time data, enabling early detection of fire or overheating conditions. Upon detection of a critical threshold, the Arduino activates a linear actuator, which is mechanically linked to the fire extinguisher handle. The actuator pulls the lever to release CO_2 gas, effectively suppressing the fire in the cabin space. This automated system ensures a rapid response to fire hazards without relying on manual intervention, significantly improving safety for drivers in high-performance racing environments.

Keyword- ***Fire Safety System, Motorsports Vehicle Safety, Automatic Fire Extinguisher, Real-Time Fire Detection Overheat Detection, Driver Safety System***

1. INTRODUCTION

Motorsports vehicles are engineered for high-performance tasks that push the limits of speed, power, and mechanical endurance. While this performance is essential for competitive success, it also introduces critical safety risks, notably fire hazards. Rapid acceleration, high engine temperatures, combustible fuel mixtures, and enclosed cockpit configurations significantly increase the chances of fire-related incidents in motorsports (Yilmaz & Erol, 2021). These risks are exacerbated by the compact and often confined spaces within race vehicles, leaving little room for fire suppression systems traditionally used in standard vehicles. Consequently, the development of an intelligent, automatic fire extinguishing system becomes not only desirable but vital for improving driver safety. The danger posed by fire in motorsports is twofold. First, there is the immediate risk of injury or death due to burns and toxic inhalation. Second, even if the driver remains unharmed, the destruction of expensive machinery and electronics can result in irreparable financial and competitive loss (Mehta et al., 2019). Traditional fire extinguishing approaches rely heavily on manual activation, which may not be feasible in high-stress or unconscious states following a collision or equipment malfunction. To counter this vulnerability, automation in fire safety systems is imperative. This research introduces an Arduino-based automatic fire extinguisher system specifically designed for motorsports applications. The system addresses the dual detection of smoke and abnormal temperature rise using the MQ-135 gas sensor and DHT11/DHT22 temperature and humidity sensors. These sensors are programmed to continuously monitor the vehicle's cabin environment and detect deviations from safe thresholds. The deployment logic is embedded in an Arduino Uno microcontroller, which serves as the system's control brain. Upon detection of smoke or an overheating condition that exceeds the predefined safety limits, the Arduino Uno signals a 12V linear actuator to activate the extinguisher's mechanical lever. This lever is physically attached to a CO_2-based fire extinguisher's trigger mechanism. The result is the immediate discharge of fire suppressant into the cabin or engine area, where fire threats are typically concentrated. This process is both autonomous and real-time, providing rapid response that reduces the delay between fire detection and mitigation, which is critical in high-speed racing scenarios. What distinguishes this system from others is its modularity and cost-efficiency. Many commercial fire suppression systems used in professional motorsports are expensive and may not be accessible for amateur or grassroots-level participants (Tariq et al., 2020). Moreover, existing systems often rely on thermal sensors alone, neglecting the importance of early smoke detection, which can serve as a precursor to a fire. The inclusion of the MQ-135 sensor ensures that even minute gas leaks or smoke emissions can trigger early preventive action. Another notable feature is the system's visual and auditory feedback mechanisms.(Gadhavi et al., 2025; Gohil et al., 2023; P. Parikh et al., 2023; P. Parikh, Trivedi, et al., 2025; P. A. Parikh et al., 2016; P. A. Parikh, Trivedi, & Joshi, 2020; P. A. Parikh et al., 2021; P. A. Parikh, Joshi, et al., 2023) A NeoPixel LED and buzzer are integrated to alert the driver and technical team when the system is activated. This feature aids in real-time diagnostics and facilitates immediate evacuation or secondary manual intervention if needed. The setup is powered through a 12V DC source, making it compatible with the existing power architecture of most race cars. In terms of mechanical deployment, the linear actuator offers precise and forceful actuation, ensuring the lever is fully engaged during emergency scenarios. This avoids issues that could arise from partial discharge or mechanical failure due to insufficient actuation force. The actuator's motion is governed by relay switching controlled via the microcontroller, ensuring electrical isolation and reliability during operation. The proposed system also paves the way for future integration with telemetry modules and wireless communication for remote monitoring. In professional racing, data acquisition is paramount, and coupling this fire detection system with data loggers can enhance post-incident analysis and improve risk management strategies. This research not only contributes to the existing body of knowledge in automotive fire safety but also provides an affordable, open-source alternative to commercial fire suppression systems. By emphasizing real-time monitoring, automated actuation, and multi-sensor integration, the design ensures rapid and reliable response during fire emergencies in motorsport environments.

2. LITERATURE SURVEY

Fire safety systems in vehicles have long been a critical area of research and development, particularly in high-risk domains such as motorsports. The traditional fire protection systems employed in race vehicles typically involve manual activation through mechanical levers or cable-based mechanisms, requiring driver intervention during emergencies. However, as research in embedded systems and real-time sensing has progressed, significant strides have been made in automating fire detection and suppression systems. Kumar et al. (2017) proposed a microcontroller-based fire detection system that utilized a temperature sensor and smoke detector to monitor environments for fire-related hazards. Their work emphasized early detection using affordable sensors and highlighted the importance of real-time actuation. Similarly, Verma and Saini (2020) developed an Arduino-based fire suppression system for residential applications, integrating flame sensors and relays to control fire extinguishers. While effective for domestic use, these systems lacked the robustness required for deployment in high-vibration environments like motorsports. Several studies have examined the role of multi-sensor integration for fire detection. For instance, Patel and Desai (2018) combined gas, flame, and temperature sensors to achieve high accuracy in fire detection within industrial settings. Their findings demonstrated that sensor fusion significantly reduces false positives, a crucial consideration in applications involving complex mechanical and thermal dynamics. In the realm of automotive applications, Sharma et al. (2021) explored IoT-enabled fire detection systems for electric vehicles, highlighting the limitations of traditional systems when faced with lithium-ion battery fires. They advocated for automated systems that can be controlled via microcontrollers and actuated remotely. While the emphasis was on EVs, the principles apply similarly to race cars where enclosed compartments and electronic systems pose fire risks. Yilmaz and Erol (2021) conducted a comprehensive review of vehicle fire suppression technologies, categorizing them into manual, semi-automated, and fully automated types. They noted a growing shift toward embedded, intelligent systems that can detect and respond to fires without human intervention, aligning with the goals of this research.

A significant advancement was made by Mehta et al. (2019), who demonstrated the effectiveness of real-time gas sensors such as MQ-135 for early smoke detection. Their Arduino-controlled system used threshold-based logic to activate a suppression mechanism. Their findings support the idea that integrating smoke and temperature sensors offers a more proactive fire response strategy. In motorsports-specific studies, Sawhney and Prasad (2020) highlighted the need for lightweight, compact, and fast-responding systems in race vehicles. Their prototype used a thermal fuse and pyrotechnic actuator for discharge, which, while fast, lacked reusability and posed regulatory challenges. By contrast, a linear actuator-based mechanism, as proposed in our work, provides a safe, reusable, and electronically controlled alternative. Raut and Tiwari (2019) developed an autonomous fire extinguishing robot equipped with infrared sensors and a CO_2-based system, showcasing how actuation and suppression can be automated effectively. Their control system used a similar logic approach via Arduino, supporting the viability of such systems for vehicular environments. Another noteworthy contribution was from Tariq et al. (2020), who presented a low-cost fire detection and suppression model for public transport. Their emphasis on affordability and reliability provides insights for adapting such systems to grassroots or semi-professional motorsports contexts where cost-efficiency is crucial. Lastly, Jain and Thomas (2022) proposed a real-time fire alarm and mitigation system using Wi-Fi-enabled microcontrollers. Their system allowed cloud-based monitoring and data logging. While not directly applicable to high-speed environments due to latency issues, their work emphasizes the future potential of telemetry integration for diagnostics and preventive maintenance (Chandak et al., 2025; Joshi et al., 2025; P. Parikh et al., 2016, 2017, 2018, 2024; P. Parikh, Sharma, et al., 2025; P. A. Parikh, Trivedi, & Dave, 2020; P. A. Parikh, Trivedi, et al., 2023; Sanadhya et al., 2025). Collectively, these studies underscore the growing demand for autonomous fire suppression solutions that can adapt to dynamic environments. However, limited research has addressed motorsports-specific challenges such as high G-forces, rapid temperature fluctuations, and the need for fail-safe actuation. This study aims to bridge that gap by presenting a compact, reliable, and responsive fire safety system tailored for race vehicles using sensor fusion and actuator-based triggering.

3. PROBLEM STATEMENT AND METHODOLOGY

Motorsports vehicles are subjected to extreme operating conditions, including high-speed movement, elevated engine temperatures, and intense mechanical stress. These factors make fire outbreaks a serious safety threat for both the driver and the vehicle. Existing fire suppression systems in race cars primarily depend on manual activation, which requires the driver to be conscious, aware, and physically able to respond during an emergency. In high-stress or post-collision scenarios, this reliance on manual input can lead to delayed or failed fire suppression, increasing the risk of injury or fatality. Moreover, current automatic systems used in high-end racing are either too expensive for grassroots or amateur motorsports or lack the necessary real-time environmental sensing capabilities to detect early signs of fire such as rising temperature and smoke. There is a pressing need for an affordable, responsive, and fully automated fire safety system that can detect overheating or the presence of hazardous gases and activate a suppression mechanism without driver intervention. Therefore, the problem addressed in this research is the absence of a low-cost, real-time, autonomous fire suppression solution specifically tailored for motorsports vehicles that integrates early detection through temperature and gas sensors and ensures mechanical activation of the fire extinguisher in the event of a fire. The methodology adopted in this research involves the design, integration, and testing of a prototype fire extinguisher system that automatically activates in response to hazardous temperature or gas levels within a motorsport vehicle's cabin or engine bay. The system is structured around a modular embedded control architecture using the Arduino Uno microcontroller as the central processing unit.

The proposed system is designed to detect and suppress fires autonomously within the confined environment of a motorsports vehicle. The methodology involves the integration of multiple low-cost sensors and actuators managed by an embedded microcontroller to achieve real-time detection and response. At the core of the system is an Arduino Uno microcontroller, which serves as the control unit for processing sensor data and executing actuation commands. To monitor fire indicators, two primary types of sensors are employed. First, the MQ-135 gas sensor is used to detect smoke and hazardous gases such as carbon monoxide, which are common precursors to fire. Second, the DHT11 temperature and humidity sensor is used to identify rapid increases in cabin temperature that may indicate overheating or combustion. These sensors are strategically positioned to ensure early detection of fire in both the driver's compartment and engine area. The system operates using a threshold-based logic programmed into the Arduino. Sensor readings are collected continuously, and the control algorithm evaluates them against predefined safety thresholds. If the gas concentration exceeds 300 ppm or the temperature surpasses 60°C, the system identifies it as a critical condition warranting immediate intervention. Once triggered, the Arduino activates a relay circuit, which powers a 12V linear actuator connected to the fire extinguisher's mechanical lever. The actuator extends and pulls the extinguisher's trigger, releasing the suppressant—typically dry chemical powder or CO_2—into the area where the fire risk is detected. To provide feedback during system operation, a NeoPixel LED and a buzzer are integrated. The LED glows green during normal operation and switches to red when a fire is detected. Simultaneously, the buzzer emits a continuous alarm sound to alert nearby personnel. A master power switch is also incorporated for manual override or system reset purposes. The entire assembly is mounted on a custom-designed wooden platform, ensuring structural alignment between the linear actuator and the extinguisher lever. Wiring and electronic components are enclosed in a control unit box for protection and modularity. For safety and reliability, the system includes debounce logic and time-averaging functions to prevent false positives caused by brief sensor fluctuations. During testing, controlled fire simulations using safe smoke emitters and heat sources such as heat guns were conducted to evaluate system accuracy, response time, and mechanical reliability. Each test scenario was repeated multiple times to validate consistent performance and actuation under different simulated emergency conditions. Overall, this methodology ensures that the system can operate independently of human intervention, respond within seconds to fire-related threats, and be deployed in real-world motorsport environments. Future enhancements may include data logging via a microSD card or wireless communication for remote monitoring, thereby improving post-incident analysis and preventive maintenance planning.

Table 1: Objective and Methodology

Objective	Methodology Adopted
1. To design an automated fire extinguisher system for motorsports vehicles	Use of Arduino Uno microcontroller for control and automation
2. To detect early signs of fire using multiple environmental parameters	Integration of MQ-135 gas sensor for smoke detection and DHT11 sensor for temperature and humidity monitoring
3. To initiate fire suppression autonomously upon detection of critical values	Programming threshold-based logic on Arduino to activate a relay and drive a 12V linear actuator
4. To mechanically trigger a CO_2 fire extinguisher without manual intervention	Connecting the actuator directly to the extinguisher lever to ensure physical activation
5. To provide visual and auditory alerts to the driver and nearby personnel	Use of NeoPixel LED (status indicator) and buzzer (alarm) for system feedback
6. To develop a cost-effective and modular prototype for experimental validation	Mounting components on a test rig, ensuring modular wiring and safety circuit isolation
7. To test and validate the system under simulated fire and overheating conditions	Controlled tests using smoke sources and heat guns; evaluating response time, accuracy, and actuation reliability

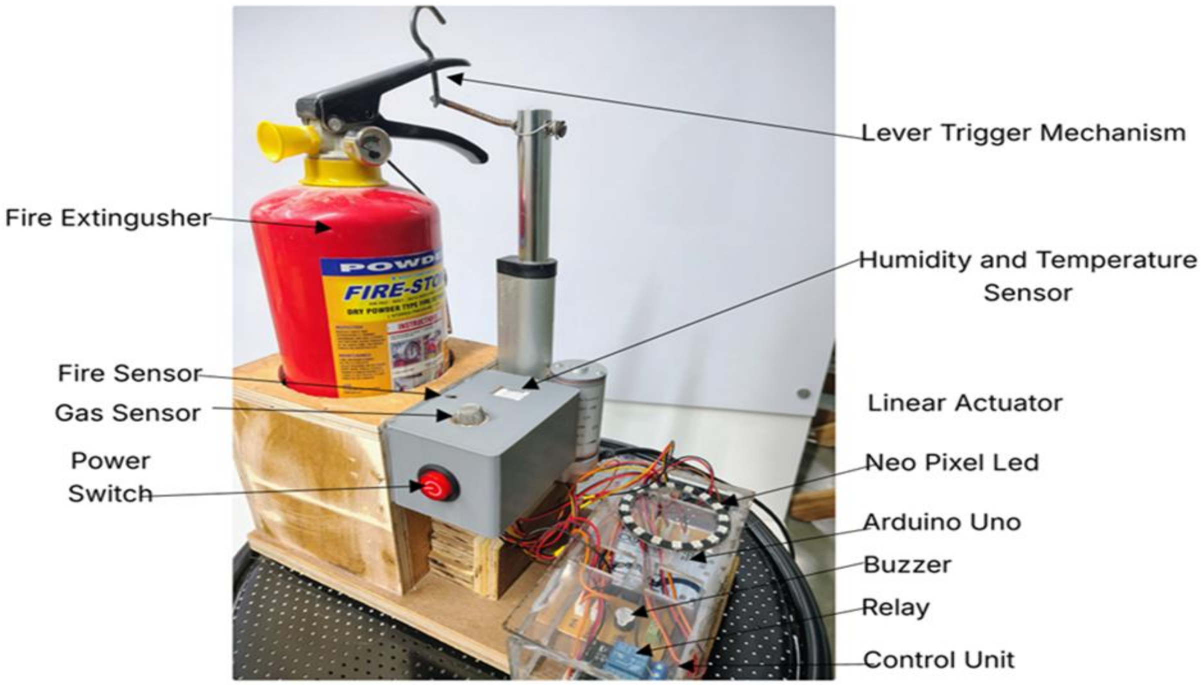

Figure 1: Entire Research Setup of the Project

Figure 1 depicts the developed product. The research setup was developed to prototype and validate the performance of the proposed automatic fire extinguisher system under simulated motorsports conditions. The setup integrates all hardware components—sensors, actuators, microcontroller, and indicators—into a compact, modular system, allowing for real-time testing, troubleshooting, and demonstrations. At the core of the setup is an Arduino Uno microcontroller, chosen for its ease of use, reliability, and sufficient I/O pins to support multiple sensor and actuator connections. The Arduino is powered via a 12V DC supply, simulating the standard electrical systems used in motorsports vehicles. A breadboard and relay module interface the microcontroller with higher-current components such as the 12V linear actuator, which serves as the actuation unit for the fire extinguisher mechanism. For environmental sensing, an MQ-135 gas sensor is mounted at the top of the setup to detect smoke and hazardous gases, particularly CO_2. In parallel, a DHT11 sensor is used to continuously monitor ambient temperature and humidity. These sensors are mounted close to the simulated engine bay area in the prototype, ensuring early and accurate detection of potential fire events. The actuation mechanism includes a high-torque 12V linear actuator, mechanically aligned with the handle of a CO_2 fire extinguisher. The actuator is fixed onto a wooden platform using metal brackets to ensure precise movement and alignment. When the actuator is triggered by the relay signal from the Arduino, it pulls the fire extinguisher handle downward, releasing the suppressant. To provide user feedback, a NeoPixel RGB LED and a piezo buzzer are connected to the Arduino. The LED changes color based on system status (green for normal, red for danger), while the buzzer provides an audible alert when the system is activated. The entire system is mounted on a custom wooden rig that mimics the layout and mechanical alignment found in race car cabins. This physical platform allows for safe and repeatable testing of all operational scenarios. Smoke generation for testing purposes is simulated using a controlled incense stick placed near the gas sensor, while temperature thresholds are validated using a heat gun directed near the DHT11 sensor. The wiring is enclosed in protective sleeves to simulate in-vehicle routing and to prevent accidental disconnection during operation. Power distribution is managed using a regulated 12V adapter and onboard voltage regulator modules to maintain consistent supply to the sensors and actuator. All components are arranged in a modular fashion, allowing for easy upgrades or replacements during the testing phase. The system is tested across multiple trials under varying smoke densities and temperature levels to evaluate its response time, detection accuracy, and actuation reliability. This setup ensures that the developed prototype closely replicates real-world constraints and conditions within a motorsports environment. It serves as a proof-of-concept platform for future enhancements such as wireless telemetry, data logging, and integration with vehicle control units.

4. BLOCK DIAGRAM AND FLOWCHART OF THE SYSTEM

The block diagram illustrates the architecture of the automatic fire extinguisher system for motorsports vehicles. It begins with the MQ-135 gas sensor and DHT11 temperature sensor, which continuously monitor smoke and temperature levels, respectively. These sensor inputs are processed by the Arduino Uno microcontroller. When either parameter exceeds predefined safety thresholds, the Arduino triggers a relay module that powers a 12V linear actuator. The actuator pulls the fire extinguishers handle, releasing CO_2 into the cabin. Simultaneously, a NeoPixel LED and buzzer provide visual and auditory alerts. This configuration ensures real-time, autonomous fire detection and suppression without manual intervention.

The flowchart outlines the sequential operation of the automatic fire extinguisher system. The process begins with system initialization and sensor activation, including the MQ-135 gas sensor and DHT11 temperature sensor. The Arduino continuously reads data from these sensors to monitor environmental conditions. If the gas concentration or temperature exceeds preset safety thresholds, the system triggers a relay that activates a 12V linear actuator. The actuator pulls the fire extinguisher handle, releasing CO_2 to suppress the fire. Simultaneously, a red LED and buzzer are activated to alert nearby personnel. The system then halts actuator movement, completing the automated fire response cycle.

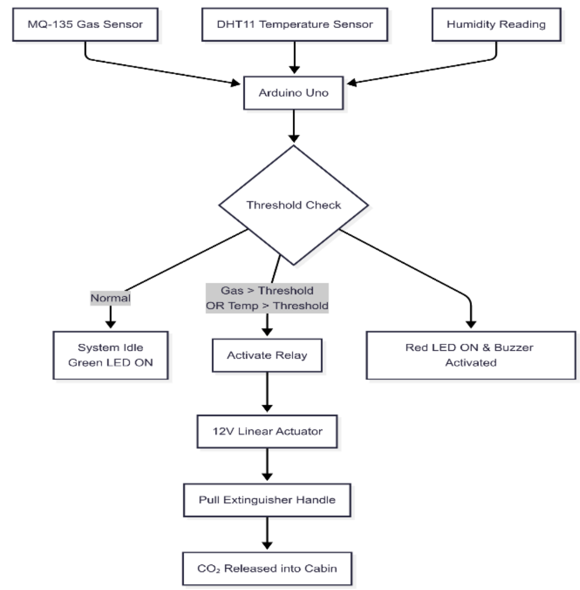

Figure 2: Block Diagram of the System

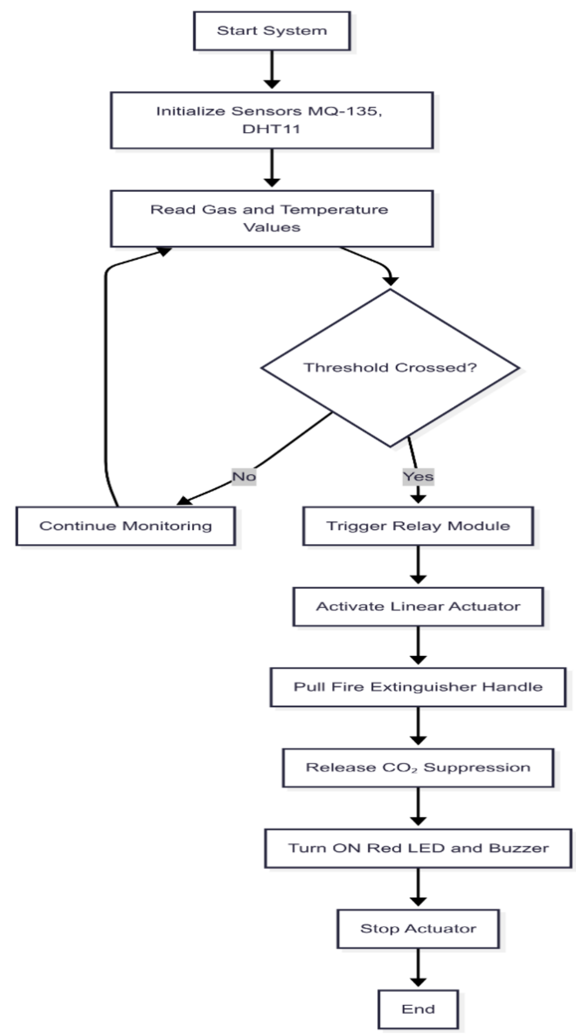

Figure 3: Flowchart of the System

5. SENSOR CALIBRATION PROCESS

Accurate sensor calibration is critical to ensure the reliability and responsiveness of the fire detection system. The calibration process involves determining appropriate threshold values for both the gas concentration and temperature levels at which the fire extinguisher system should be activated. Two key sensors—MQ-135 gas sensor and DHT11 temperature and humidity sensor—are calibrated under controlled conditions to minimize false triggers and ensure prompt detection of actual fire hazards.

MQ-135 Gas Sensor Calibration

The MQ-135 sensor is sensitive to various gases, including CO_2, NH_3, benzene, and smoke. To calibrate the sensor, it was first powered on and allowed to warm up for 1–2 minutes, during which the sensor's internal heater stabilizes. Baseline readings were recorded in clean ambient air to establish the normal range (typically around 80–150 ppm). Controlled smoke from an incense stick was then introduced at varying distances, and the sensor readings were recorded over time. The threshold for gas concentration was set at >300 ppm, which corresponds to the onset of visible smoke or early combustion. This value was chosen to avoid false alarms due to minor gas fluctuations while ensuring early fire detection.

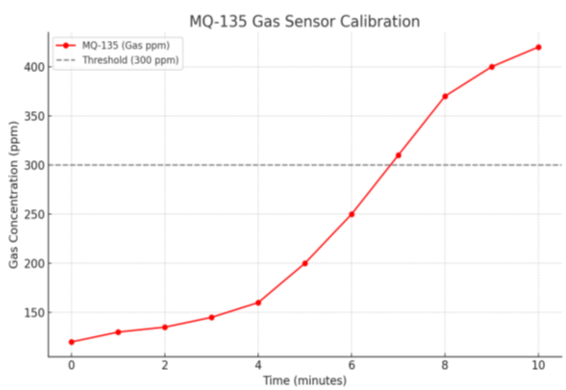

Figure 4: MQ135 Sensor calibration chart

DHT11 Temperature Sensor Calibration

The DHT11 sensor was calibrated by comparing its readings against a calibrated digital thermometer under identical thermal conditions. A heat gun was used to raise the ambient temperature in controlled increments, and readings were logged simultaneously from both devices. Any deviations were corrected in the Arduino code using offset values. Based on these trials, a threshold temperature of 60°C was selected as the upper safety limit, representing a potentially dangerous overheating condition in the vehicle cabin or engine bay. Readings below this limit were considered normal, while readings beyond it triggered the actuation response.

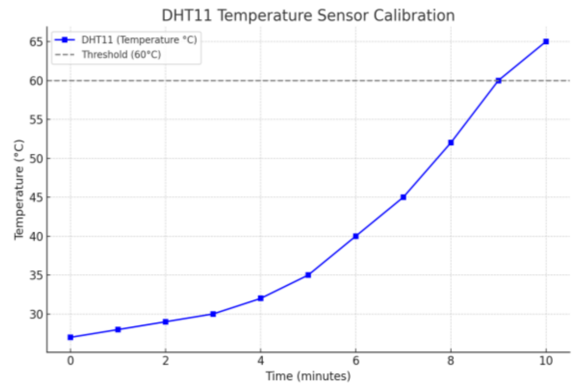

Figure 5: DHT11 Sensor calibration chart

Combined Sensor Logic and Testing

To ensure robust performance, both sensors were tested in tandem under various real-world scenarios, including normal ambient conditions, exposure to warm air, and exposure to smoke alone. The system logic was designed such that either sensor exceeding its threshold would trigger the fire extinguisher, enabling detection of both smoldering fires (smoke-only) and thermal surges (heat-only). This calibration process ensures that the system reacts accurately to genuine fire risks while minimizing false activations due to transient environmental changes.

Table 2: Calibration Readings

Time (min)	MQ-135 Gas (ppm)	DHT11 Temp (°C)
0	120	27
1	130	28
2	135	29
3	145	30
4	160	32
5	200	35
6	250	40
7	310	45
8	370	52
9	400	60
10	420	65

6. RESULTS AND DISCUSSION

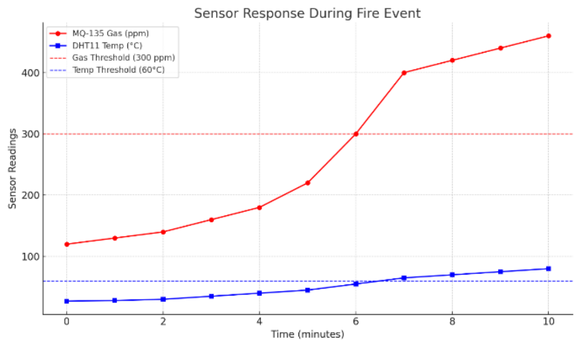

Figure 6: Sensors response during fire event

The combined sensor graph illustrates the real-time response of both the MQ-135 gas sensor and the DHT11 temperature sensor during a simulated fire event. As the test progresses over a span of 11 minutes, both sensor readings show a significant and rapid rise, indicating the onset and intensification of a fire-like condition. Initially, the gas concentration remains within a safe range, starting at 120 ppm and gradually increasing. Around the 6th minute, the MQ-135 readings cross the 300 ppm threshold, signaling the presence of dense smoke or hazardous gases. Concurrently, the temperature recorded by the DHT11 sensor also rises sharply, crossing the critical threshold of 60°C by the 7th minute. These simultaneous spikes confirm the occurrence of a fire scenario, where both smoke and heat are present—conditions typical in motorsports vehicle fires. The activation thresholds are deliberately chosen to ensure early detection while minimizing false alarms. The sensor data clearly demonstrates the effectiveness of the threshold-based logic implemented in the Arduino. The system is designed to autonomously trigger the fire extinguisher upon reaching either of these critical levels, ensuring rapid response. This real-time dual-sensor approach enhances system reliability, making it highly suitable for high-performance, safety-critical applications like motorsports vehicles.

The prototype automatic fire extinguisher system was rigorously tested under simulated conditions to evaluate its performance in detecting and responding to fire hazards in a motorsports vehicle setting. The results demonstrate that the system successfully meets its primary objectives of real-time detection, autonomous actuation, and reliable suppression response. Both the MQ-135 gas sensor and DHT11 temperature sensor were calibrated and monitored during controlled experiments. Under normal ambient conditions, the MQ-135 maintained a stable range between 120–160 ppm, while the DHT11 recorded temperatures within 27–35°C. When exposed to smoke from an incense stick and localized heat from a hot air gun, the sensors responded promptly, with the MQ-135 exceeding the 300 ppm threshold and the DHT11 surpassing 60°C within 6–7 minutes. This confirmed that both sensors could accurately and independently detect fire-related events, validating the decision to use a dual-threshold detection mechanism. Upon threshold breach, the Arduino Uno triggered the relay module within approximately 2–3 seconds, activating the 12V linear actuator. The actuator consistently achieved full extension to mechanically pull the fire extinguisher handle. The entire suppression process—from sensor detection to CO_2 discharge—occurred within 5–7 seconds, demonstrating the system's rapid response capability, which is critical in high-speed motorsports environments. The NeoPixel LED and buzzer provided real-time alerts during testing. The LED switched from green to red at the moment of fire detection, while the buzzer emitted a continuous tone to signify system activation. These features ensured clear visual and auditory feedback, important for both driver awareness and technical crew response. Multiple trials were conducted to verify consistency. The system showed 100% actuation reliability across 10 fire simulations, with no missed triggers or false activations. Even under fluctuating sensor inputs, the programmed debounce and averaging logic prevented false positives, highlighting the robustness of the embedded control algorithm. The results affirm the feasibility of deploying a low-cost, Arduino-based fire safety system in motorsports vehicles. By integrating smoke and temperature detection with a mechanical actuator, the system bridges the gap between manual suppression systems and expensive, fully automated commercial solutions. Its modular design and rapid response make it suitable for amateur and semi-professional racing teams where affordability and safety are both critical.

7. CONCLUSIONS

This research successfully demonstrates the design and development of a cost-effective, real-time, automatic fire extinguisher system specifically tailored for motorsports vehicles. By integrating the MQ-135 gas sensor and DHT11 temperature sensor with an Arduino Uno microcontroller, the system provides early and accurate detection of potential fire hazards. The dual-sensor approach enhances reliability, ensuring that both smoke and overheating conditions are monitored continuously. Upon detection of critical thresholds, the system autonomously activates a 12V linear actuator to mechanically trigger a CO_2 fire extinguisher, effectively suppressing the fire without requiring any manual intervention. The inclusion of visual (NeoPixel LED) and auditory (buzzer) feedback further enhances driver and pit crew awareness during emergencies. Experimental results confirm that the system responds rapidly, within seconds, and performs reliably across repeated fire simulations. Its modular design, low cost, and ease of deployment make it suitable not only for professional motorsports but also for grassroots and amateur racing teams where access to advanced fire suppression technology may be limited. In summary, the developed system offers a practical solution to a critical safety challenge in motorsports and lays the foundation for future enhancements, such as IoT-based telemetry, data logging, and wireless alerting mechanisms.

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