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Development of Engine Fire Protection System for Vehicle

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Abstract

Engine fires in vehicles pose significant hazards to passengers and the environment, necessitating the development of an engine fire suppression system to enhance vehicle safety. This study aims to propose a technique for detecting and suppressing engine fires at an early stage and validate its functionality. The research objectives include designing a system consisting of a Fire Detection Unit (FDU) and a Fire Suppression Unit (FSU) and evaluating its effectiveness. The materials used for the study included IR flame sensors, a temperature sensor, and a CO2 fire suppression system. Standard procedures were followed in conducting experimental trials using a cubic test rig simulating the engine compartment. Key findings from the analysis of the designed system indicate that the FDU's flame sensors trigger a warning when the analog output falls below the threshold of 100, while the temperature sensor triggers a warning above 50°C. The FSU exhibited reliable functionality, with consistent extinguishing times ranging from 4.91s to 5.42s. Data analysis confirms the system's accuracy, with precision values ranging from 0.9499 to 0.9963. In summary, this study successfully developed an engine fire suppression system and demonstrated its effectiveness in detecting and suppressing engine fires. The findings suggest that the proposed technique can significantly contribute to enhancing vehicle safety. Future work may involve further optimizing the system design such as addition of CO_2 gas sensor, transitioning from analog CO_2 regulator to digital CO_2 regulator and adding a subsystem to ease maintenance work.

1. Introduction

Vehicles with internal combustion engines require cooling systems to manage the combustion-generated heat. Nevertheless, fuel leaks, electrical failures, and engine attrition can cause engine fires. This initiative aims to implement a fire protection system inspired by aviation in automobiles, allowing for the prevention and suppression of engine fires. The system would be remotely controlled by the driver and employ fire-suppressing agents, providing an essential safety measure for vehicle occupants and mitigating environmental hazards associated with engine fires.

Conventional car fire extinguishers, typically available in 1kg or 2kg sizes, have limitations in effectively combating engine bay fires [1], [2]. Their design constraints hinder close-range deployment and require opening the hood, posing risks such as backdraft, an explosive event caused by sudden oxygen supply to a burning space [3]. In October 2022, multiple fire incidents resulting in fatalities and injuries were reported [4], [5], often involving direct impacts to the engine bay, which houses critical components like electronics, fuel lines, and the combustion chamber. These incidents highlight the need for improved fire safety measures in vehicles.

This research seeks to accomplish three goals. First, it proposes a method for suppressing engine fires at an early stage without the need to open the bonnet of a vehicle. Second, the researchers intend to use Arduino to create a model of an engine fire detection system for vehicles. Finally, they intend to undertake tests and evaluate the model's functionality.

This research focuses on three main scopes. Firstly, it aims to identify and locate critical areas within the engine compartment where fires are more likely to start, in order to enhance the effectiveness of fire extinguishing efforts. Secondly, the researchers plan to integrate two flame sensors and a temperature sensor onto an Arduino UNO 3 board, developing a prototype of the system. Thirdly, the research aims to incorporate the use of LEDs and a buzzer to provide immediate alerts to the driver in the event of a fire outbreak in the engine compartment. Lastly, for functionality evaluation, the threshold value for flame sensors is set to < 100, 50°C for temperature, and 60 psi for regulator output pressure.

According to studies, fuel that has leaked or spilled is what starts most car fires after collisions [6]. This fuel can be ignited by sparks from the impact, electrical arcing, or hot surfaces. The location of fuel system components and the sort of impact can have an impact on the likelihood and intensity of a fire. Compared to frontal or rear-impact collisions, side-impact collisions are more likely to result in fires. Additionally, research focuses on creating technologies and materials to improve vehicle fire resistance, such as enhanced fuel systems, fire-resistant materials in the vehicle's construction, and sophisticated sensors and control systems for quickly spotting and putting out fires.

Next article published by Boeing, discusses commercial aircraft's fire suppression systems. Using materials like fireproofing, barriers, and coatings, passive systems stop the spread of fire and safeguard structures. Engine and power unit fire detection and suppression employing detectors and extinguishing agents are examples of active systems [7]. Newer materials and technologies offer increased fire resistance, but proper design and location are essential for their performance.

Lastly, in the automotive sector, fire-resistant materials are essential for improving passenger safety. They provide people more time to evacuate and lower the risk of injury and fatalities on the road by preventing the quick spread of fire after collisions or electrical failures. Heat shields, ceramic fiber, and intumescent materials are examples of frequently used materials that operate as barriers to stop or slow down the flow of heat. Robustness, resistance to corrosion, and exceptional fire resistance are all characteristics of composite materials like carbon fiber and aramid fiber composites (Kevlar) [8], [9].

The development of this work is based on the implementation of available methods and technologies applied on different platform of vehicles such as aircraft with suitable sensors and methods for fire detection and extermination in engine compartment of a vehicle.

2. Methodology

The hardware and components utilized throughout an Arduino Uno R3, Groove flame sensors, DS18B20 temperature sensor, LEDs, buzzer, SPST toggle switch, 12V DC solenoid, CO2-based fire extinguisher, CO2 regulator, and stainless-steel nozzles.

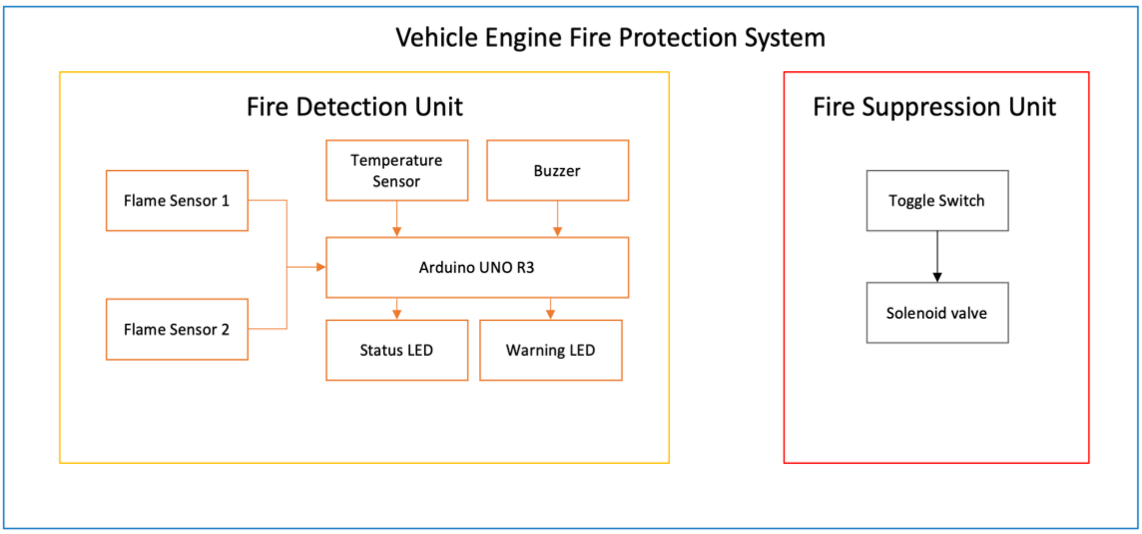

Fig. 1 *Block diagram of the whole system*

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Fig. 1 shows the block diagram for the vehicle engine fire protection system. Inside it consist of two units the Fire Detection Unit (FDU) and the Fire Suppression Unit (FSU). FDU contains three inputs which are two IR flame sensors & a temperature sensor. As for the output, there are three outputs utilised in this unit which are the buzzer, Warning LED and the Status LED. Moving onto the FSU, this unit only contains one input which is the toggle switch and one output which is the solenoid valves.

Fig. 2 depicts an engine protection system designed to detect and extinguish fires. Initialization of the system is the initial stage in ensuring that the system is prepared to perform its intended purpose. A status LED is illuminated after system initialization to indicate that the system is operational and prepared to monitor for fire. The system then scans the values of the flame sensors, which detect the presence of a fire. If either sensor 1 or sensor 2 detects a fire, or if both sensors detect a fire, the status LED is deactivated, a warning LED is engaged, and a buzzer is activated. The same goes for the temperature sensor which will trigger the FDU when the temperature exceeds 50 °C. These measures are taken to inform the user of the presence of a fire and to urge necessary actions. The user can extinguish the fire through a manual input by opening the solenoid valve through a toggle switch. The solenoid valve is responsible for releasing a fire extinguishing agent to put out the fire. When the fire is extinguished and the flame sensors no longer sense it, the process complete.

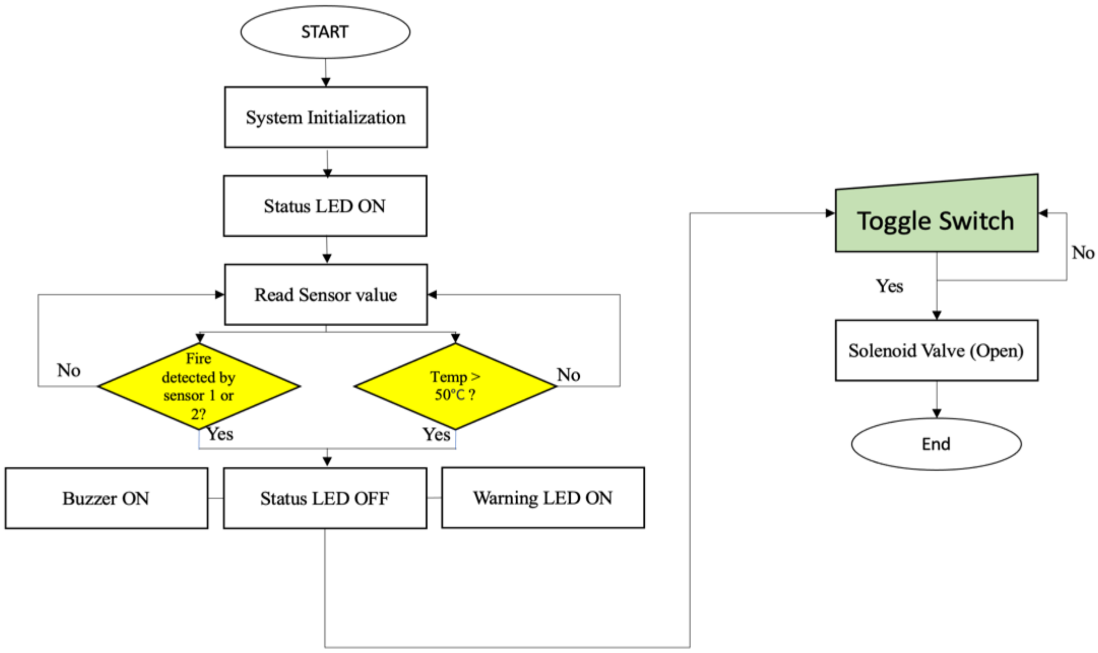

Fig. 2 *System flowchart*

In this work, the circuit layout were made using fritzing software. It provides a virtual circuit overview of the designed system. The layout for FDU and FSU is been portrayed in Fig. 3 and 4, respectively.

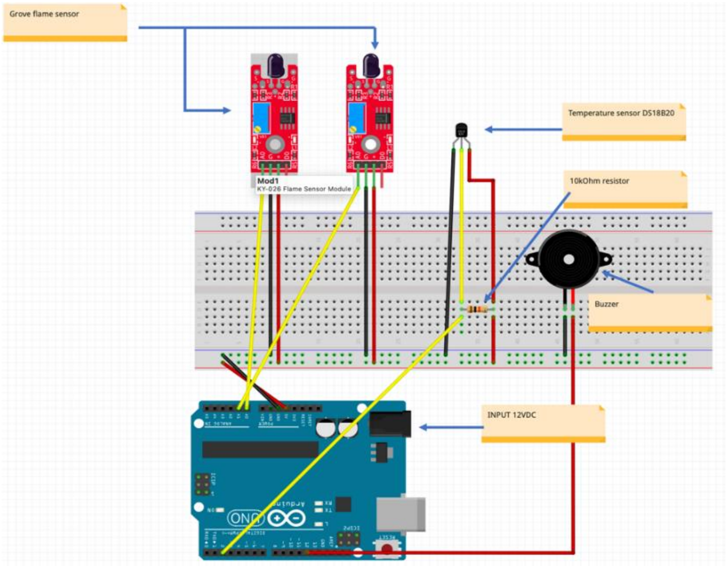

Fig. 3 *Virtual circuit of fire detection unit (FDU)*

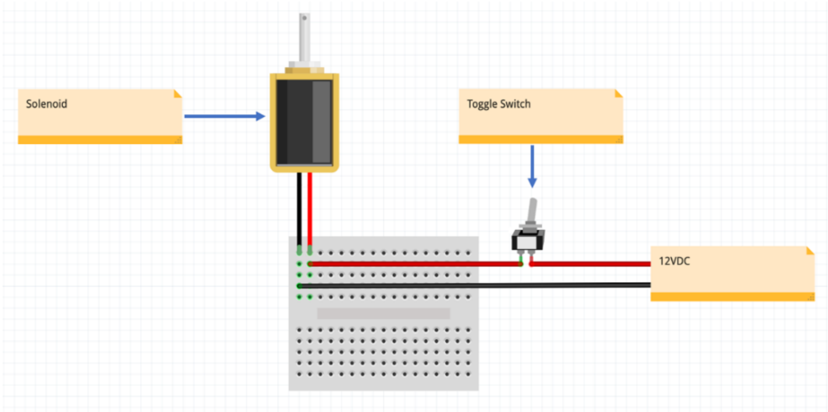

Fig. 4 *Virtual circuit of fire suppression unit (FSU)*

In order to imitate the enclosed and limited nature of the engine compartment, the experiment will be conducted in a cubic test rig measuring 1 ft by 1 ft by 1 ft. The test rig as shown in Fig. 5, composed of aluminium, is designed to counterbalance the intense heat emitted by the flame during the flame detection and extinguishing test. It features a removable glass panel to facilitate observations and a lid that can be opened at the top, enabling convenient access during the test and for installation of sensors into the rig.

Fig. 5 *Test rig*

The flame sensor operates and communicates with the Arduino in analog signal. So, an analog to voltage conversion is needed to determine the voltage level represented by the analog value if needed. The conversion equation is in (1) as follows.

$$Voltage\ (V) = \frac{Analog\ Value}{V_{ref}} \qquad Eq.1 \qquad (1)$$

As for the temperature sensor, conversion of output voltage to degree Celsius (°C) can be done by utilising the equation (2) [11].

$$Temperature(°C) = \frac{Voltage(mV) + 0.1\mu}{0.021} \qquad Eq.2Temperature(°C) = \frac{Voltage(mV) + 0.1\mu}{0.021} \qquad Eq.2 \qquad (2)$$

The arithmetic mean as shown in equation (3), also known as average, is a statistical measure that reflects the central tendency of a dataset comprising numerical values. It is determined by summing up all the values within the dataset and dividing the resulting sum by the total count of values. This measure will be utilised in calculating the average time taken for FSU to extinguish the fire.

$$\bar{x} = \sum_{n=1}^{n} x_n \ , \qquad Eq.3 \qquad (3)$$

where $\bar{x}$ is arithmetic mean, x_n is the value of *n*th measurement, *n* is the total number of readings.

Deviation from the mean is referred to as the difference between each piece of data and the mean. The deviation value may be in positive or negative however the algebraic sum equal to zero. This will be utilised to calculate the deviation of each test data on time taken to extinguish the fire. Deviation from the mean is expressed as in equation (4) [13]:

$$d_n = x_n - \bar{x}\ , \qquad Eq.4 \qquad (4)$$

where x_n is the value of *n*th measurement and $\bar{x}$ is the arithmetic mean.

Precision refers to the measure of consistency or repeatability of a measurement where a quantitative or numerical indication of the closeness with which a repeated set of measurements of the same variable agrees with the average of the set measurement. Precision is obtained by the equation (5) as follows [14].

$$Precision = 1 - \left|\frac{x_n - \bar{x}}{\bar{x}}\right| \ , \qquad Eq.5 \ (5)$$

where x_n is the value of *n*th measurement and $\bar{x}$ is the arithmetic mean.

3. Results and Discussion

This section comprises of all the test results for functionality test on FDU and FSU.

3.1 FDU functionality test through flame sensors

Referring to Fig. 6, when no fire is detected, both flame sensors value is more than the designated threshold of < 100. When fire is detected by sensor 1, the readings for sensor 1 drops to 32 which is below the threshold and FDU is activated as per Figure 7. When sensor 2 detects the present of fire, the sensor readings drop to 32 which is below the threshold hence lead to the activation of FDU as per figure 8. Summary of this test is provided in Table 1.

Fig. 6 *Flame sensor value when no fire present*

Fig. 7 *Flame sensor 1 value when fire present*

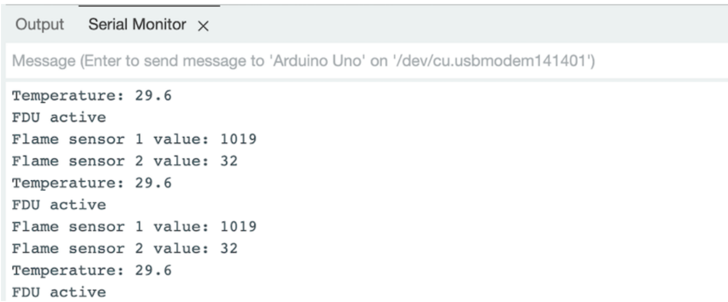

Fig. 8 *Flame sensor 2 value when fire present*

Table 1 *Summary of functionality test through flame sensor*

Analog output (Threshold)	Digital output	FDU auditorial and visual warning (buzzer and red LED)
>100	1	OFF
<100	0	ON

3.2 FDU functionality test through temperature sensor

The threshold for the temperature is set to 50°C throughout the test. The test is conducted by dipping the temperature sensor in hot water. Referring to Fig. 9, when the temperature is below the designated threshold of 50°C, FDU is in standby state. Once the temperature passes the 50°C threshold as per Fig. 10, a change is seen on the state of the FDU where it transitioned from 'standby' to 'active'. Summary of this test is provided in Table 2.

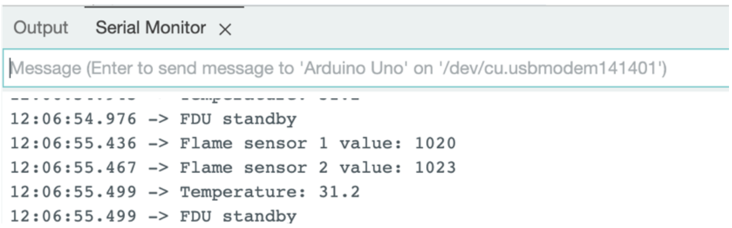

Fig. 9 *Output from serial monitor when temperature is <50*°C

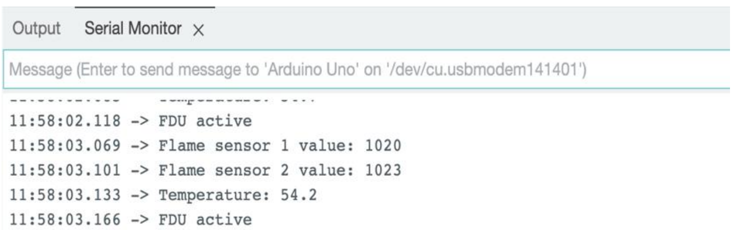

Fig. 10 *Output from serial monitor when temperature is >50*°C

Table 2 *Summary of functionality test through temperature sensor*

Temperature (°C)	FDU auditorial and visual warning (buzzer and red LED)
>50	ON
<50	OFF

3.3 Functionality test on FSU

Functionality test on FSU is conducted by lighting up approximately 10ml of kerosene. Table 3 shows the data collected throughout the test. Referring to Table 3, the table presents comprehensive data on extermination time measurements obtained from 10 samples. The recorded extermination time ranges from 4.91 to 5.42 seconds, indicating a tightly clustered distribution of values. This suggests a consistent duration for the extermination process across the conducted tests. The deviation values represent the disparities between each recorded time and a reference value. Negative deviations (ranging from -0.2590 to -0.0190) signify extermination times shorter than the reference value, while positive deviations (ranging from 0.0410 to 0.2510) indicate longer durations.

Table 3 *Data of fire extermination test*

Test	Extermination time (s)	Deviation (s)	Precision
1	4.91	-0.2590	0.9499
2	5.21	0.0410	0.9921
3	5.13	-0.0390	0.9925
4	5.27	0.1010	0.9805
5	5.35	0.1810	0.9650
6	5.15	-0.0190	0.9963
7	5.08	-0.0890	0.9828
8	5.42	0.2510	0.9514
9	5.11	-0.0590	0.9886
10	5.06	-0.1090	0.9789
Total	51.69	0.0000	-
Mean	51.69	0.0000	-
Standard deviation	-	0.1490	-

The precision values associated with the tests serve as indicators of result accuracy. The range of precision values, spanning from 0.9499 to 0.9963, implies highly precise and accurate overall measurements. The precision values closer to 1 reflect a high level of accuracy in calculating extermination times. Fig. 11 shows the graph of deviation vs precision. The graph indicates that the precision remains consistently high (close to 1) regardless of the deviation, which suggests that the measurements are accurate and precise across the range of deviations.

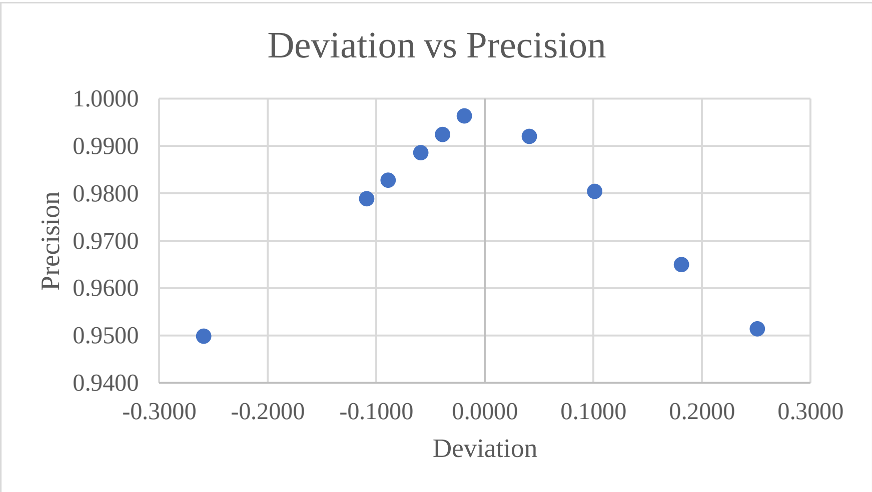

Fig. 11 *Deviation vs. Precision graph*

An examination of the summary statistics reveals that the cumulative extermination time for all ten tests amounts to 51.69 seconds, with an average time of 5.169 seconds. This average value reinforces the notion of consistent extermination times. The standard deviation of 0.1490 underlines the extent of variability in the recorded times. Although the deviation from the mean is relatively small, it signifies a moderate degree of dispersion in the data, suggesting some variations in the duration of the extermination process across the tests.

4. Conclusion

In conclusion, the development of the engine fire protection system model has been successful, achieving all objectives. The Fire Detection Unit (FDU) effectively alerts the driver through audible and visual warnings, while the Fire Suppression Unit (FSU) grants the driver control over deploying the CO_2 fire extinguishing agent. The sensors demonstrate accurate and reliable performance, providing timely information for optimal system functionality.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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