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DESIGN AND IMPLEMENTATION OF A FIRE DETECTION AND CONTROL SYSTEM FOR AUTOMOBILES USING FUZZY LOGIC

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ABSTRACT
The immense benefits of fire detection in road transport cannot be overemphasized. The proposed work consist of design of fire detection system in automobile using Ardino microcontroller using fuzzy logic based monitoring and control system to avoid damages due to fire in automobiles. The automatic system consisting of flame sensors, temperature sensors, smoke sensors and a re-engineered mobile carbon dioxide air-conditioning unit for testing of a medium sized physical car. An innovative, very promising solution module for hardware implementation in fire detection and control for automobiles will be developed by using new algorithms and fuzzy logic.

KEYWORDS: fire detection, fuzzy logic control, reengineering, air-conditioning.

INTRODUCTION
Automobile industries are constantly defining and refining manufacturing techniques and services to avoid combusting their loyal customers. Yet for reasons ranging from fuel efficiency, manufacturing cost reduction, durability, through comfort and safety to aesthetics, motor vehicles are made with several potential ignition sources with prevalent threats of fire outbreak. Proactive manufacturers occasionally institute recalls to avert some of these threats of fire outbreak. These actions also result in billions of dollars in revenue losses. These fires causes many deaths and injuries every year. It is very important to study the problem of automobile fire outbreak to gain better understanding of and effectively deal with the burning of automobiles. Three means are employed in dealing with the problem of fire outbreak in automobiles and transportation in general. These are fire prevention, fire minimization and fire suppression.

Fire prevention mainly deals with employing effective design principles to curb operational interferences that may lead to fire outbreak. This may involve but not limited to choice of materials, materials geometry and form of orientation in relation to other materials. Fire minimization concerns itself with employing fire resistant materials in locations where there is the likelihood of fire propagation. Most automobiles have fire resistant materials serving as firewalls to protect the passenger compartment from engine compartment fire. These firewalls are now perforated with openings to allow the flow of pipes, cables and wires not seen on older automobiles. Fire suppression aims at extinguishing active fire. Most fire suppression systems require some form of contact with the fire to be more effective. Engine compartment fires sometimes knock off the bonnet locking mechanism making fire suppression more difficult in automobiles. Toxicological effects of burning cars and the ability of egested fumes to prevent escape from fire environment and induce death have long been issues of grave concern. Many resources have been directed at passenger escape or rescue from automobile fire outbreaks, leaving costly cherished vehicles prone to thermal insults, which render motor vehicles useless in 20 minutes. Abandoned and stationary vehicles are often at the mercy of arsonists and rioters. Several standards have been enacted to date but the problem of automobile fire has not been fully addressed. Combustion is defined as a self-sustaining chemical reaction between fuel and an oxidant evolving into heat, flame (light), smoke and fire gases. In the motor vehicle, the fuel in a combustion process may range from liquid/gaseous

fuels, transmission and engine oils, power steering and brake fluids, coolant and refrigerant, upholsteries, foams and plastic materials such as in dashboards, bumpers and wire insulations, tyres, any material being conveyed by the vehicle and probably the chassis itself. To save combustible material (automobile) from burning; oxygen, heat and the chain reaction components must be dealt with. Oxygen can be replaced directly by spray of carbon dioxide. Carbon dioxide mobile air-conditioning system used to remove heat and retardants injected into stream of carbon dioxide to halt the chemical reaction altogether. Yet electrical system failures are known to be the second most common cause of automobile fires next only to fuel leakages. Common fire classes are A, B, C and D. Class A fires are extinguished using water. Class B fires are oil-based whereas class C fires are electrical in nature. Automobile fire is one of class B, class C or both and is extinguishable by the right quantity of carbon dioxide delivered to the fire source. Current mobile air conditioning systems run on R134a refrigerant. Carbon dioxide (C02), known as R744 when used as refrigerant is at least 1300 times less handful to the climate than the fluorinated greenhouse gas R134a. It is established for mobile air-conditioning system that carbon dioxide is a good refrigerant that employs a more robust mechanical system of refrigeration. According to the National Highway Traffic Safety Administration, once fire starts in the engine, it takes an average of 4 minutes for the fire to reach the passenger compartment. Fire from rear end of vehicle reaches passenger compartment in 2 minutes and it takes 10 to 15 minutes for fire and rescue service to arrive at the scene. It is showed that when fire was deliberately set to vulnerable parts of the automobile engine, it took 12 minutes to cause appreciable damage. With the current computational power of microcontrollers, working in microseconds, the whole process of fire detection and control can be completed under 30 seconds of real time. Most of the successes of fuzzy logic controller design can be traced to various implementations in automotive engineering. In recent years, fuzzy logic is becoming a common technology in this field, mainly because, optimization of various complex control systems with multiple parameters using fuzzy logic incorporates engineering expertise of years of testing rather than mathematical models. By nature, fuzzy logic is time invariant and nonlinear, able to handle complex nonlinear control problems with multiple parameters compared to other multi-parametric systems, fuzzy logic is often computational and code-space efficient. Fuzzy logic systems work by if-then rules, which are interpreted by decision-making algorithms into real situations. As a fast growing technology gaining international acceptance, fuzzy logic instruction sets are incorporated into microcontrollers at the manufacturing level. Fuzzy logic have been applied and used in different detection schemes. In two fuzzy linguistic variables with six linguistic values each, representing temperature and aerosol detected from fire were used in a fire alarm system for high-rise buildings.

PROBLEM IDENTIFICATION AND SCOPE OF WORK

Problem Statement
To monitor and detect fire in automobile system using various sensors such as Flame , Temperature and Smoke sensors. Design of fire control system in automobile with proper tuning of fuzzy logic parameter.

Scope of Work
The fuzzy logic is becoming a common technology in this field, mainly because, optimization of various complex control systems with multiple parameters using fuzzy logic incorporates engineering expertise of years of testing rather than mathematical models.

## SYSTEM &METHODOLOGY

Design Methodology
The automobile fire detection and control system has two major subsystems namely: fire detection subsystem (network of sensors) and fire control subsystem (carbon dioxide distribution network). The fire detection subsystem is further divided into engine and fuel tank subsystem and cabin and boot subsystem. Figure 4.1 shows the various sub modules.

Figure:**System architecture with the various modules and interfaces.**

Figure:**Flowchart for fire detection and location**
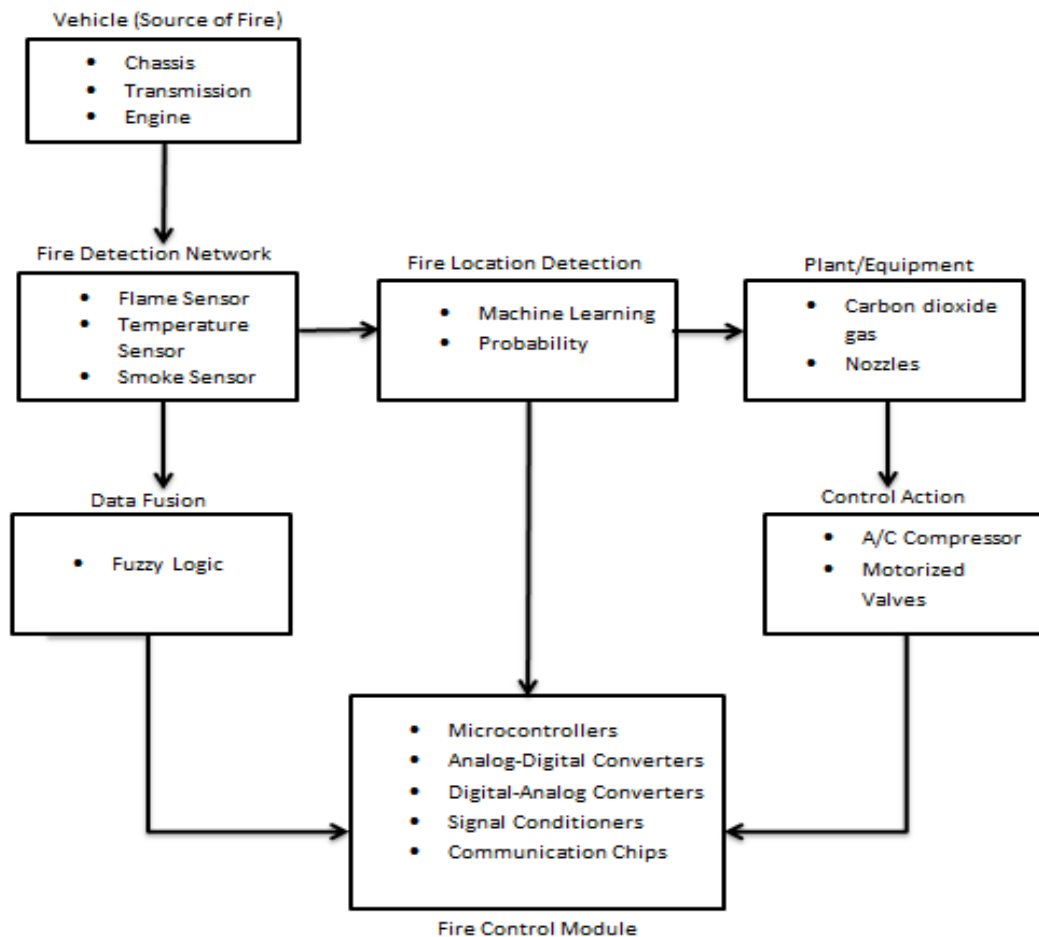
The engine ambient and exhaust/catalytic high temperatures demand different temperature threshold from the more humane atmosphere within passenger cabin and boot. The control subsystem becomes dependent on the fire detection subsystem for appropriate compressor valve addressing through an Arduino microcontroller.
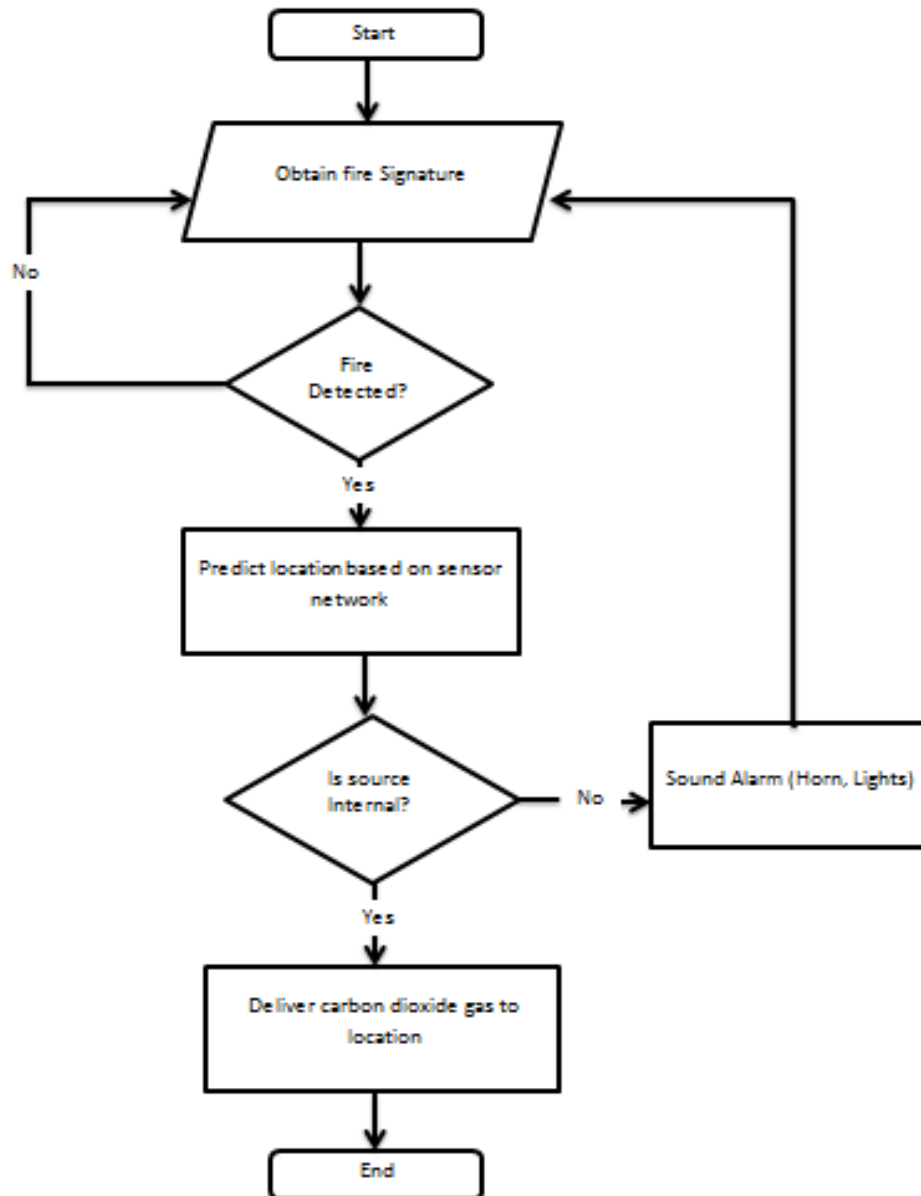
For any automobile equipped with the developed system, the chassis, transmission and engine compartments susceptible to fire outbreaks are networked together through the fire detection network through fire signatures such as heat, flame and temperature. The data obtained from reading of the sensors within the network are fused together as inputs for microcontroller processing and action. Based on automatic location of fire through the sensed parameters, the embedded fuzzy logic processes the data and initiates control action by opening of valves for fire extinguishment.

Mathematical Foundations for Fire Detection- Introduction to Fuzzy Logic

Fuzzy logic has been chosen to decide exact location of fire. Because fire could rise in any location within the monitored area. Since the number of sensors to detect the fire are mounted on different positions of the sensor deployment area, sometimes detecting the fire location precisely becomes difficult. Without the fuzzy logic from the actual readings of the adjacent sensors, relative position of the fire can be determined. Since, the

exact angle from three or four different sensors mounted in different location, one single location point can be estimated. However, it does not provide satisfactory results in various scenarios specially whenever the range of the sensors are less and if there is large number of sensors. For larger area monitoring with inexpensive short range sensors this type of situation can easily happen. Hence, fuzzy logic algorithm has been incorporated in to SFF system. Fuzzy logic is used in servo motor library for fire extinguisher handling purposes. It determines the exact angle to target the fire position. Appropriate location is determined based on the fuzzy logic and considering intensity of adjacent sensors readings mounted in different positions. Thus servo motor point the exact location of the fire and release fire extinguisher.

Fuzzy set is a set of ordered pairs given by

$$A = \{(x, \mu_A(x)): x \in X\}$$

where X the universe of discourse, $\mu_A(x)$ the grade of membership of x in A and, $\mu_A(x)$ lies in the interval [0,1]. The shapes of popular membership functions are triangular, trapezoidal, Gaussian etc. The triangular and trapezoidal membership functions are illustrated in figures 4.4 and4. 5. The only restriction being that these functions take values between [0, 1]. Experience helps in determining suitable functions for particular scenarios. A triangular membership function illustrated in figure 4.4 is fully specified by three parameters (a, b, c) as follows:
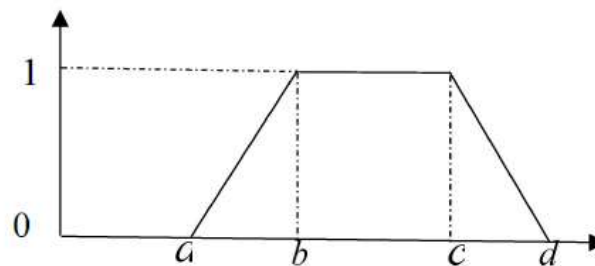
$$triangle(x: a, b, c) = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{b-a} & a \leq x \leq b \\ \dfrac{c-x}{c-b} & b \leq x \leq c \\ 0, & c \leq x \end{cases}$$

Figure: Triangular membership function
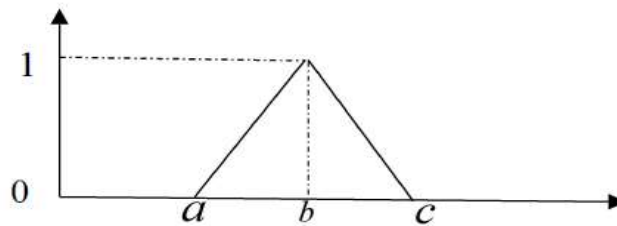
A trapezoidal membership function is specified by four parameters (a,b,c,d) as follows:
Figure: Triangular membership function

$$triangle(x: a, b, c, d) = \begin{cases} 0, & x \leq a \\ \dfrac{x-a}{b-a} & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \dfrac{d-x}{d-c} & c \leq x \leq d \\ 0, & d \leq x \end{cases}$$

Fuzzy control rules
Let x_1, x_2, x_3 be the Fuzzy Logic Controller (FLC) inputs and y the output.

$$x_1 = A_{1i} \qquad i = 1,2,3$$

Where $$x_2 = A_{2j}, \qquad j = 1,2,3 \qquad and \ y = O_{ijk}$$

$$x_3 = A_{3k} \qquad k = 1,2,3$$

The fuzzy relationship $R = \bigcup(A_{1\,jk} \times A_{2\,ik} \times A_{3\,ij}) \times O_{ijk}$

Fuzzy output

After defuzzification, the output is given by the expression

$$y = \frac{\sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{3} d_{ijk}\mu_{A1i}(x_i)\mu_{A2j}(x_j)\mu_{A3k}(x_k)}{\sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{3} \mu_{A1i}(x_i)\mu_{A2j}(x_j)\mu_{A3k}(x_k)}$$

Table 1: Fuzzy variable declaration

Linguistic Variables	*Linguistic Values*		
	Inputs		
Temperature	*Low(Lt)*	*Medium(Mt)*	*High(Ht)*
Flame	*Nearest(Nf)*	*Close(Cf)*	*Distant(Df)*
Smoke	*Low(Ls)*	*Optimal(Os)*	*Thick(Ts)*
	Output		
Action	*Stand by(Sb)*	*Alarm(Al)*	*Spray(Sp)*

HARDWARE
Figure: Cabin and sensor network for fire detection
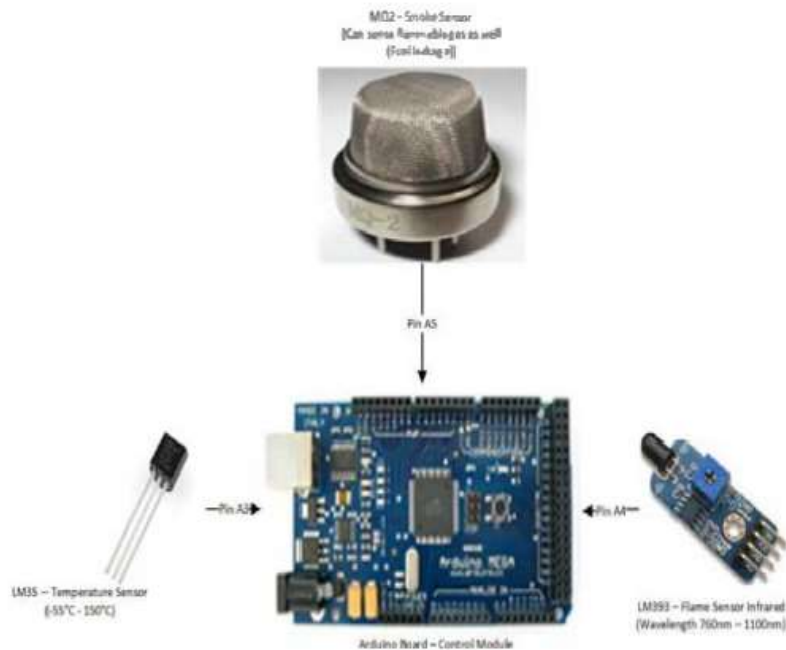
The control system design follows the incremental approach, allowing developmental changes to fit smoothly into the design process. Two fire detection networks connect to a single carbon dioxide extinguisher backbone. The carbon dioxide release network services the fire detection subsystems by responding to instructions from an Arduino Mega board. Each fire detection subsystem contains two sets of fire monitors that scan two of the four zones around the vehicle continuously for fire signatures. These fire signatures being smoke (and/or flammable gases), temperature changes and flames. Depending on ambient characteristics, temperature sensors picked for the engine compartment and exhaust gas circulation zones, were distinct from those selected for passenger and boot compartments. On detecting fire, the system alerts the vehicle user by turning on the horn and hazard lights before extinguishing it by releasing C02 refrigerant gas at the fire location. The controller

accomplishes this by means of a fuzzy logic controller software designed and embedded on the Arduino Mega board. After thorough requirement analysis the following were considered crucial.

CONCLUSION

Assurance that fire outbreak has no more fatal consequences in the automobile and especially in electric cars where the thousands of battery cells powering the vehicle tend to overheat, catch fire and explode brings new quality to road transport safety. Algorithms derived from sound reasoning ideas have been implemented and can be tested, using fuzzy logic technology embedded on an Arduino board. Automobile fire can be detected and extinguished effectively without driver's intervention and is devoid of false alarms based on current testing. This multi-sensor fire detection and control is a useful low cost sophisticated system, which can also be tested and deployed on other systems where air-conditioners can be installed. With system's excellent performance under 20 seconds, it is expected that system will pose no threat to human life although more extensive testing might be needed. Moreover, building an incorporated functionality that deals with prognosis of the health of sensors will be beneficial to the real-time detection and control of in-vehicle fires and serve as mode for preventive maintenance. Actual system implementation in vehicles without existing mobile carbon dioxide air-conditioning compressors should be done with the 2Kg cylinder mounted in the upright position, preferably behind the rear seats of the passenger cabin.

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