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SYSTEMATIC DEVELOPMENT OF AN AUTONOMOUS ROBOTIC CAR FOR FIRE-FIGHTING BASED ON THE INTERACTIVE DESIGN APPROACH

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Abstract

Fire incidences are classed as catastrophic events, which mean that persons may experience mental distress and trauma. The development of a robotic vehicle specifically designed for fire extinguishing purposes has significant implications, as it not only addresses the issue of fire but also aims to safeguard human lives and minimize the extent of damage caused by indoor fire occurrences. The primary goal of the AFRC is to undergo a metamorphosis, allowing it to operate autonomously as a specialized support vehicle designed exclusively for the task of identifying and extinguishing fires. Researchers have undertaken the tasks of constructing an autonomous vehicle with robotic capabilities, devising a universal algorithm to be employed in the robotic firefighting process, and designing a fuzzy controller algorithm that can be used in all expected scenarios. The use of a fuzzy logic algorithm in this design demonstrates the usefulness of this system, all factors are involved in which cases are previously identified and taught, as well as the overall map of the premises have been uploaded so that the system can identify the exact place of the fire source, and two types of fire have also been examined. When the performance of the foam pump, water pump, and robotic car motors is compared to the data from the flam sensor, temperature sensor and GPS data, it demonstrates a high responsiveness in terms of applying the appropriate approach based on the type of fire due to the probable action for which the system has been trained. This will have the benefit of shortening the required process for fire extinguishment and using the appropriate fire extinguishing tools. This technology may be used to put out flames, deploy in different areas, and handle a variety of fire scenarios inside buildings.

Keywords: fire-fighter robot, fuzzy controller, flam sensor, temperature sensor, GPS data.

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1. Introduction

Automation has a prominent role in the modern commercial, industrial, and domestic domains [1]. The concept involves the systematic arrangement of multiple elements to efficiently manage, guide, perceive, and govern operations with the goal of achieving a desired result. A robot is a self-governing apparatus that performs tasks often associated with human or machine operations characterized by repetitive or flexible sequences of activity. Numerous academic investigations have substantiated the potential advantages associated with the integration of robots in the fields of medicine and rehabilitation [2–6], rescue operations [7, 8], and industry [9, 10]. Over the course of a period, the incorporation of robotics has been widely adopted across many sectors within the business community. Industrial robots are versatile manipulators designed for the purpose of handling specialized materials, components, tools, or devices through the execution of programmed movements, enabling them to perform a diverse array of tasks [11]. Given its potential to result in loss of life, significant damage to property, and long-term physical and psychological harm to individuals involved, a fire incident can be classified as a catastrophic occurrence. Furthermore, individuals may potentially encounter enduring emotional anguish and trauma. Based on data provided by the International Association of Fire and Rescue Services (CTIF), it has been determined that the United States witnessed about 16,190 fatalities resulting from fires during the period spanning from 2012 to 2016. The ratio exhibits a notable disparity when compared to the ratios seen in other sources of casualties [12]. **Fig. 1** illustrates the statistical data pertaining to casualties in the United States during the years 2012 and 2016.

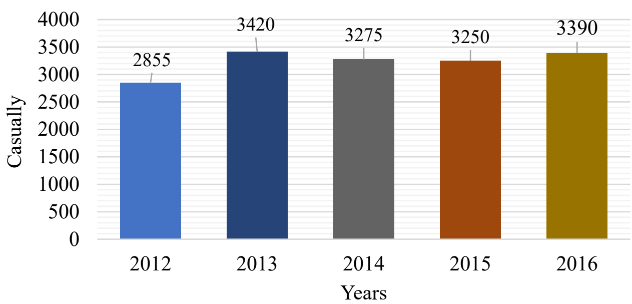

Fig. 1. Fire casualty Data [12]

The primary factors contributing to this issue include the level of public attention regarding fire safety and the insufficiency of fire detection technologies and control systems. The fire stages, as delineated by the International Fire Service Training Association (IFSTA), encompass incipient (ignition), growth, fully formed, and decay [13]. These stages are contingent upon the interplay of heat, oxygen, and fuel sources. According to existing literature, the primary factors contributing to fires in buildings encompass several elements such as culinary activities, smoking, and short circuits [14]. **Fig. 2** depicts the various causes of fires throughout different regions.

Special attention must be given to fire hazards related to electrical systems, as they are responsible for a significant proportion of fire accidents on a global scale. The primary causes of electrical fires encompass several components such as cords (including extension and appliance cords), plugs, panel boxes, branch circuits, receptacle outlets, and overload, among others. The primary causes of electrical fire dangers are loose contacts, short circuits resulting from various factors, arcs, poor electrical installations, and ineffective circuit breaker operations [16–18]. The primary indicators of a fire encompass the presence of heat in the surrounding environment, the existence of flames, the quality of air, the emission of smoke, and the observation of air-track patterns. Firefighters are generally responsible for managing fire events; yet, they frequently encounter heightened risks while extinguishing fires, particularly in perilous settings like nuclear power plants, petroleum refineries, and petrol tanks. In addition, individuals are confronted with additional challenges, particularly in instances where fire outbreaks transpire within confined and constricted spaces. In such circumstances, it becomes imperative to meticulously navigate through the debris of structures and overcome various hurdles to effectively suppress the fire and rescue any individuals in distress. The fire sensing system is employed in many appliances to detect and alert individuals to the presence of a fire hazard. **Fig. 3** depicts the fire sensing system, which roughly aligns with existing fire sensing systems.

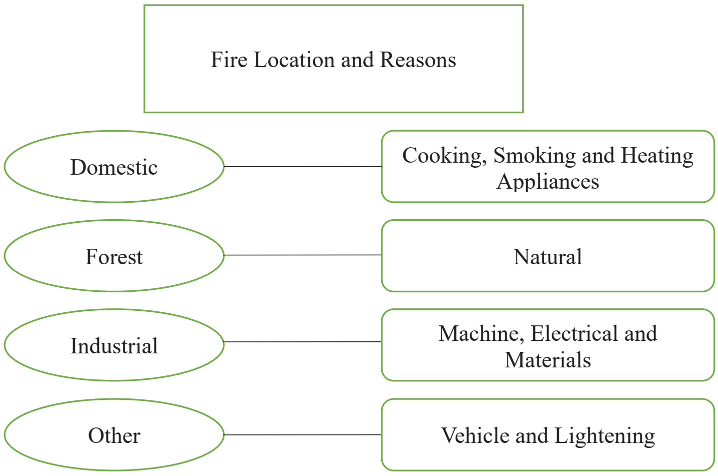

Fig. 2. Different fire reasons and location [15]

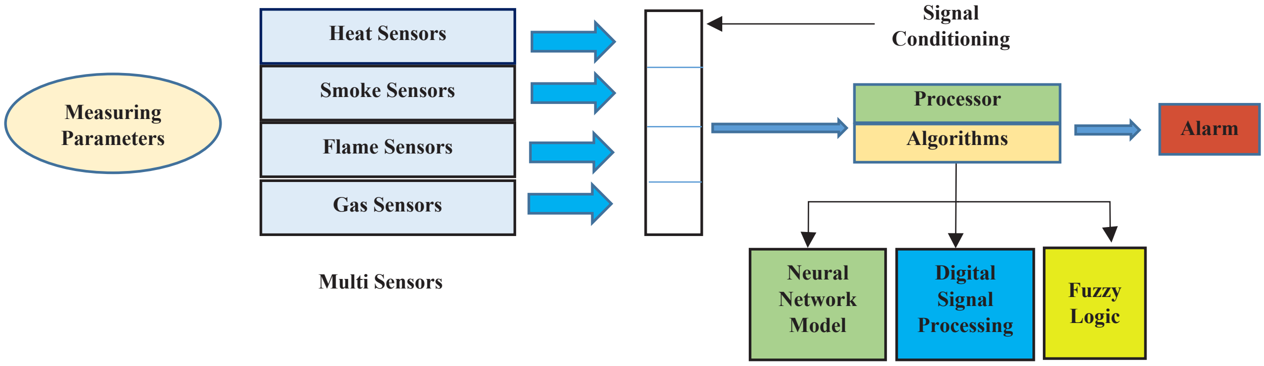

Fig. 3. Fire sensing system [19]

The fire sensing system is comprised of a multi-sensor technique for the detection of fires. The processor processes the signal conditioned output of these sensors in a proper manner. The system incorporates appropriate techniques such as fuzzy logic and neural network. When a fire hazard occurs, an alert is triggered. In contemporary society, the significance of machines and robotic design in assisting human beings has grown increasingly prominent. Hence, the integration of a fire protection robot equipped with sensors into a security system is seen a crucial necessity in human existence. Given its ability to identify and alert deviations from the norm, a robot equipped with a security system capable of detecting abnormal and hazardous situations is expected to see significant demand in the market due to its inherent use for human beings. The Fire Protection Robot has been designed with the purpose of assisting individuals in situations of destructive fires.

This robotic device possesses the capability to promptly extinguish areas affected by fire through the utilization of an autonomous system as stated in [20].

Some trend in the research field have been recorded in terms of Design of firefighter robot. The field of fire fighter robot implementation has seen significant improvements with the use of Saff robotics, which has a dual controlling portion. This system has demonstrated the effectiveness of applying both autonomous and manual movement for the goal of extinguishing fires. This system's inability to use only the water needed for the procedure as specified in [21] has been noted. Additionally, as mentioned by [22], some trends in the use of firefighter robots have been implemented by using sensors, controlling them, and using water pumping for extinguishing fires. However, none of these trends have been applied to the implementation of an autonomous robot that has all the tools necessary to put out a fire.

This project proposes the implementation of an autonomous firefighting robotic car (AFRC). The major objective of the AFRC is to undergo a transformation process, enabling it to function as an independent support vehicle specifically engineered for the purpose of locating and extinguishing fires. The AFRC has demonstrated the ability to successfully extinguish a simulated residential fire. The technology in question is an automated entity that use active search algorithms to detect instances of flame occurrence as it traverses a simulated floor layout. In the event of an emergency, the AFRC has the capability to function as a fire extinguisher, in addition to its primary role as a trail guide. Additionally, its purpose is to identify and prevent fires from escalating beyond manageable levels. A wide range of vehicle kinds are presently accessible for the purpose of mitigating home fires and extinguishing forest fires. The proposed Autonomous Fire Response System (AFRC) has been designed to possess self-sufficiency and efficacy in combating a diverse range of fire incidents. This methodology enables the identification of fires and the execution of rescue operations with enhanced safety measures, hence mitigating risks faced by firefighters. In alternative terms, the implementation of AFRC has the potential to reduce the need for firemen to engage in perilous circumstances. In addition, the robot's capacity for autonomous control and compact dimensions render it well-suited for deployment in hazardous environments such as tunnels or nuclear power plants, where the occurrence of fires has been documented [23, 24]. The objective of this study pertains to the categorization of the AFRC design, which possesses the capability to discern fires and employ distinct fire extinguishing agents, namely water and foam, based on the specific fire type.

The components of the AFRC are enumerated and elaborated upon in the subsequent sections.

2. Material and Methods

The primary focus of the design and development process of the AFRC entails the implementation of the system platform. The technology in question must possess enough durability to withstand outdoor conditions. To optimize the design, it has been suggested that the integration of microprocessors with the drive motors and steering motors be implemented, enabling a mediated control of the mobile platform. Based on the rationale, the selection of a (RC) truck is attributed to its convenient capacity for upgrading various components, including the addition of sensors, actuators, and the mounting of microprocessors. Furthermore, it is imperative to facilitate the installation of microcontrollers while also ensuring their ability to accommodate and handle the supplementary load of mobile devices, microcontrollers, sensors, and actuators. The remote-controlled truck should possess the capability to modify its suspension spring rate through the replacement of the original springs with springs of differing levels of stiffness. This feature would allow for the optimization of the vehicle's performance on uneven surfaces and its ability to handle high speeds.

A basic four-wheel drive (4WD) vehicle has been chosen to be integrated with an Arduino microcontroller. The vehicle can be operated remotely using an Android phone or tablet over a Bluetooth connection. This is achieved by utilizing a speed control application, which allows the user to manage the vehicle's speed. Additionally, the vehicle can be maneuvered using the accelerometer feature of the mobile device, as depicted in **Fig. 4**. As the system design and robotic fire fighter movement inside any premises has been nominated from previous research which it shows the handiness of using a firefighter robot inside the closed buildings as stated in [25].

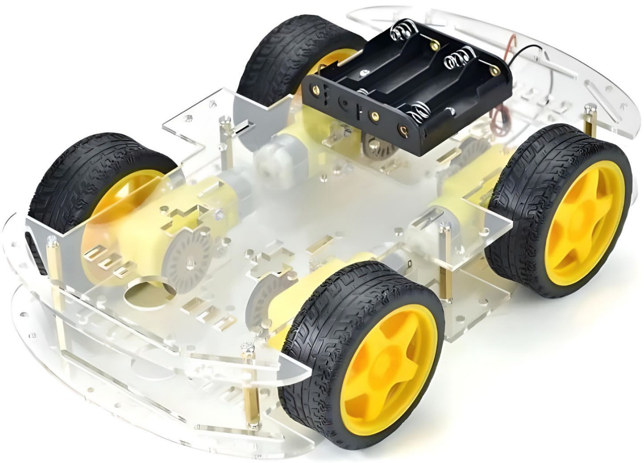

Fig. 4. Four Wheel Driver (4 WD)

2. 1. Controller unit

The primary objective of AFRC design is to ensure that the microcontroller is compact and lightweight, enabling it to be mounted on the robot platform. Additionally, it should possess enough processing speed to effectively interpret sensor data and promptly respond to input commands in real-time. The system structure is depicted in **Fig. 5** which it has illustrating the parameters employed in the design of the AFRC.

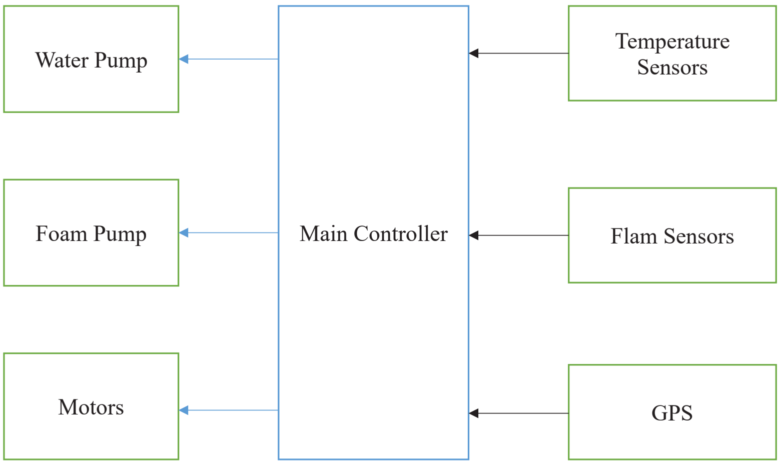

Fig. 5. AFRS controller unit schematic diagram

A fuzzy controller system has been involved with the proposed system in which the parameters of the input signal gained from (Flam, Temperature, and Dust sensor) are matched with gathered data from GPS used to identify the position of AFRS are compared with reference set of data and compared based on Fuzzy algorithm to identify the using of water or fuel pumps as well as instruct the AFRS to move toward the source of fire.

2. 2. System Design

The utilizing of Fuzzy logic algorithm in this design shows the handiness of this system in which it is a heuristic approach which pay towards making the appropriate decision for the process of operations based on specific rules. The overall algorithm is illustrated as shown in **Fig. 6**.

Where the controller has divided into two main mechanism with more than 20 rules that have been utilized to make a control for the three main input data and make the appropriate design and make the process of firefighting process more than accurate and fast in case of normal controller.

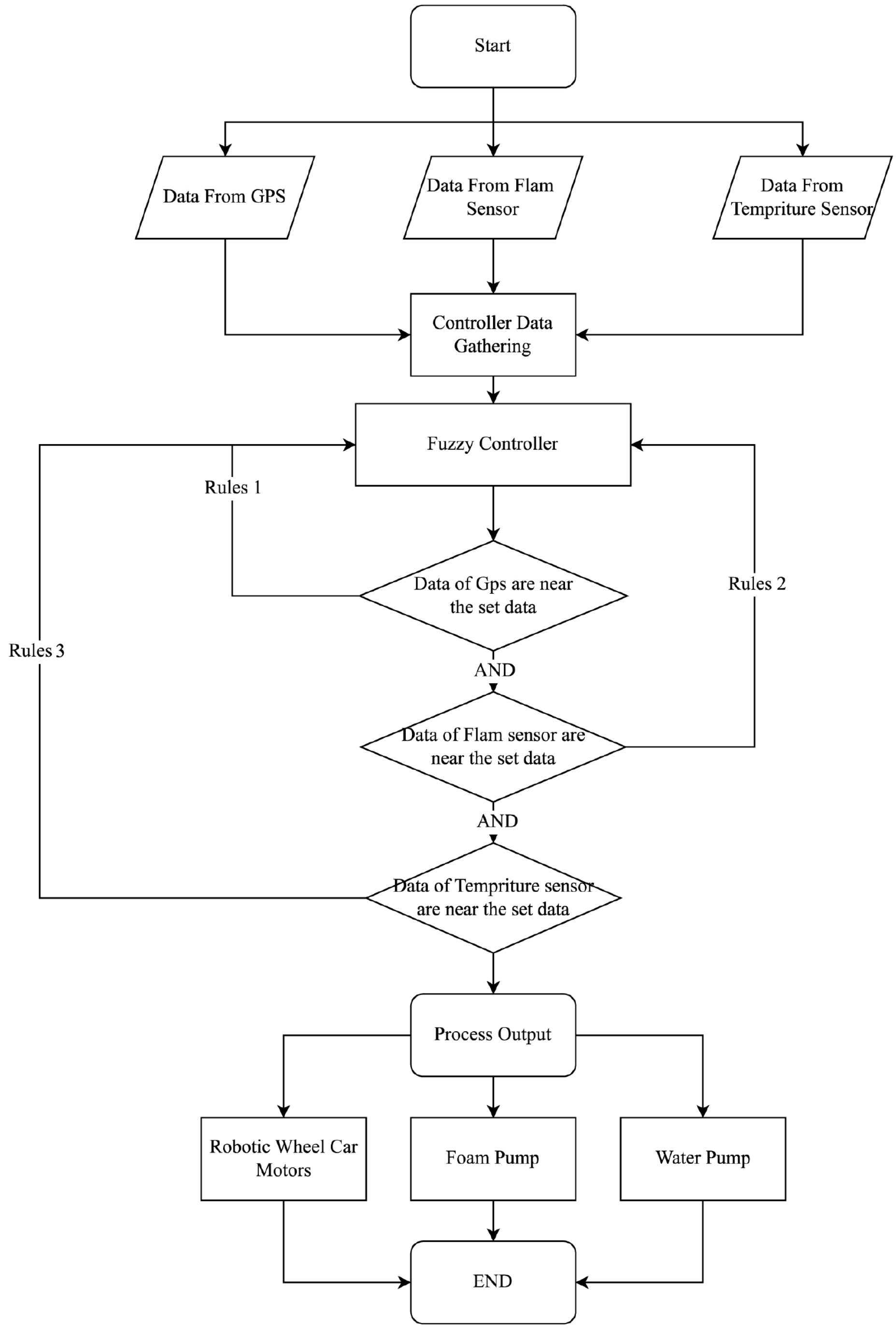

Fig. 6. System overall algorithm

The process of firefighting using the AFRS is implemented in the following points:

1. Automated Firefighting Robotics system has been launched to start firefighting process.

2. Data from GPS, Flam sensor and Temperature sensor are gathered to start the controlling of AFRS to make the desired process.

3. Data are involved in the Fuzzy controller with 20 Rules to identify the correct and suitable output.

4. Output will be identified for three different processes:

a) flam pumping;

b) water pumping;

c) robotic car wheel motors.

Where the Flam Pumping, Water Pumping and Robotic Car wheel motors are launched as the comparison of data from (Flam sensor and Temperature and GPS) has accomplished and decision has made, **Fig. 7** shows the comparison of rules for Mamdani fuzzy rules.

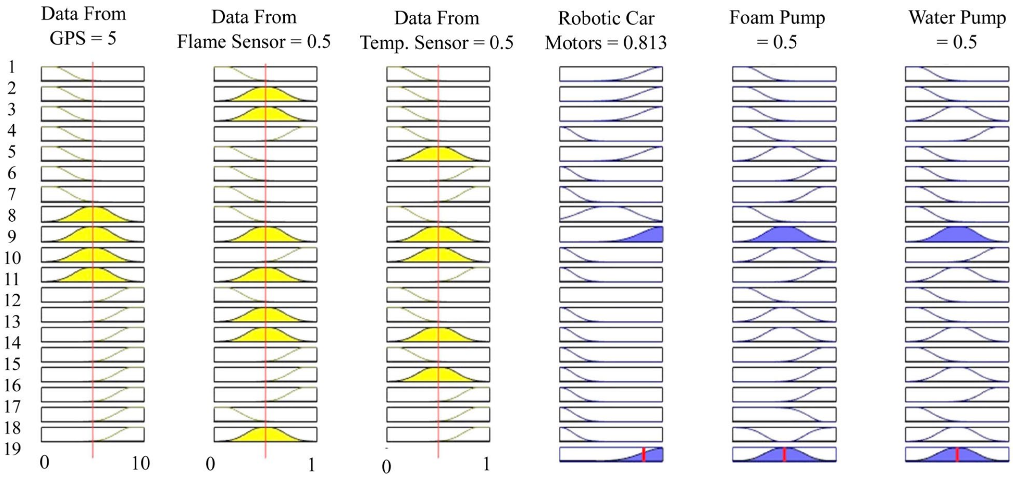

Fig. 7. Mamdani rules for three input and three output parameters

This system, all parameters are involved in which cases are identified and trained previously as well as the overall map of the premises have been uploaded so that the system can identified the exact position of fire source in addition two type of fire also have been considered.

Moreover, this system shows the handiness in terms of firefighting extension and expansion where more sensor can be involved to make the appropriate design for using the suitable material of fire-extinguishing tools.

3. Result and discussion

The process of examine the system efficiency has been examined for two cases:

– System programming based on Foam Pump.

In which the system behavior has been examined in terms of Foam pump with all input data and this comparison has been illustrated as shown in **Fig. 8**.

As comparing the performance of foam pump, water pump and robotic car motors with the data of flam sensor and GPS, it shows a high response in terms of using the suitable method according to the type of fire due to the possible action which has the system been trained. This will make the benefit of reducing the required time for fire extinguishing, as well as reduce the used resources and tools according to the type of fire, as well as overcome the problem of wasting fire extinguishing tools and using them accurately.

– System programming based on Water Pump.

The system behavior has been examined in terms of water pump with all input data and this comparison has been illustrated as shown in **Fig. 9**.

As comparing the performance of water pump and robotic car motors with the data of flam sensor and GPS, it shows a high response in terms of using the suitable method according to the type of fire due to the possible action which has the system been trained. This will make the benefit of reducing the required time for fire extinguishing, as well as reduce the used resources and tools according to the type of fire, as well as overcome the problem of wasting fire extinguishing tools and using them accurately.

The response of foam pump, water pump and robotic car motors with the data gathered from (foam, temperature sensors and GPS) have been illustrated in the below **Fig. 10**.

As noticed the variation between *I*/*P* and *O*/*P* parameters have different shape and behavior, due to the variation in terms of programmed rules, where the response of water pump output different from foam pump output. In this case the relationship has more than one action towards the process of fire-extinguishing. Furthermore, the robotic car motors are always on and ready to move and looking for the appropriate position based on gathered data from flam and temperature sensors and the position of fire.

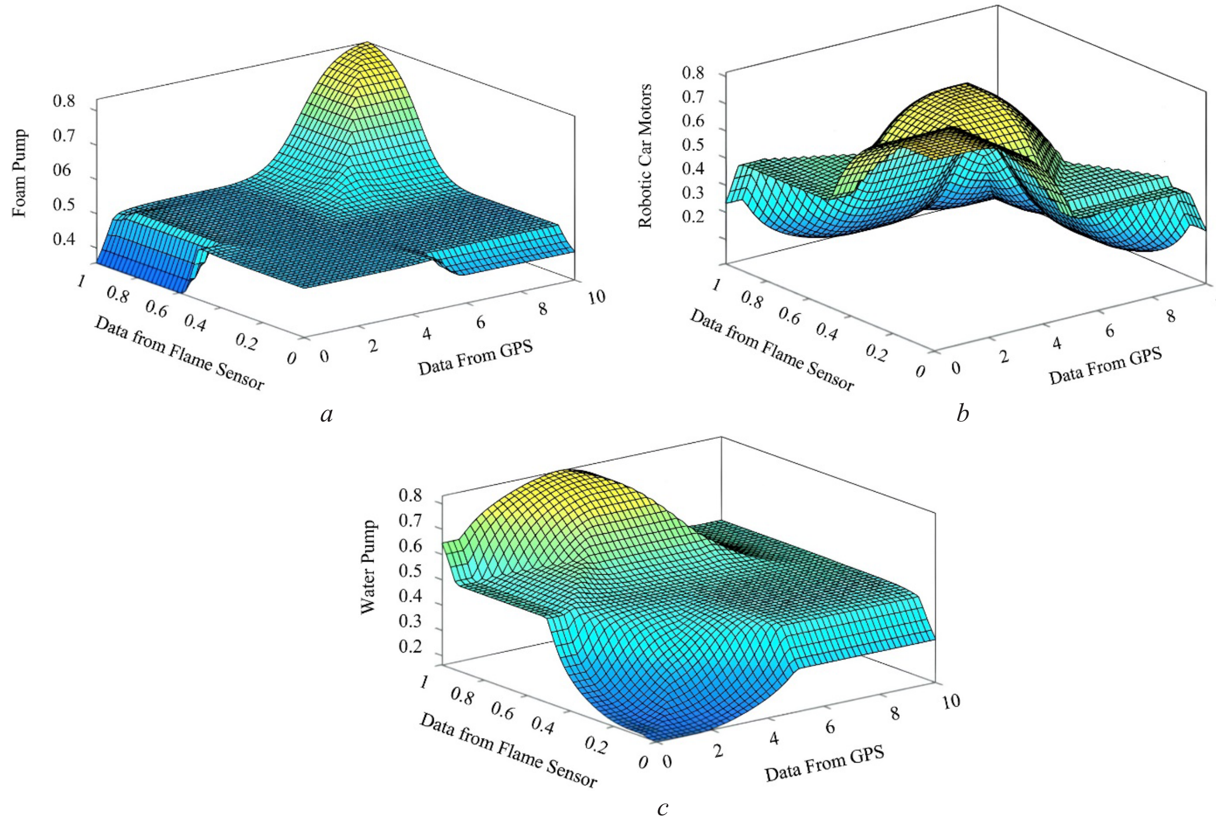

Fig. 8. Controller performance:
a – foam pump with I/P; *b* – water pump with I/P; *c* – motors with I/P

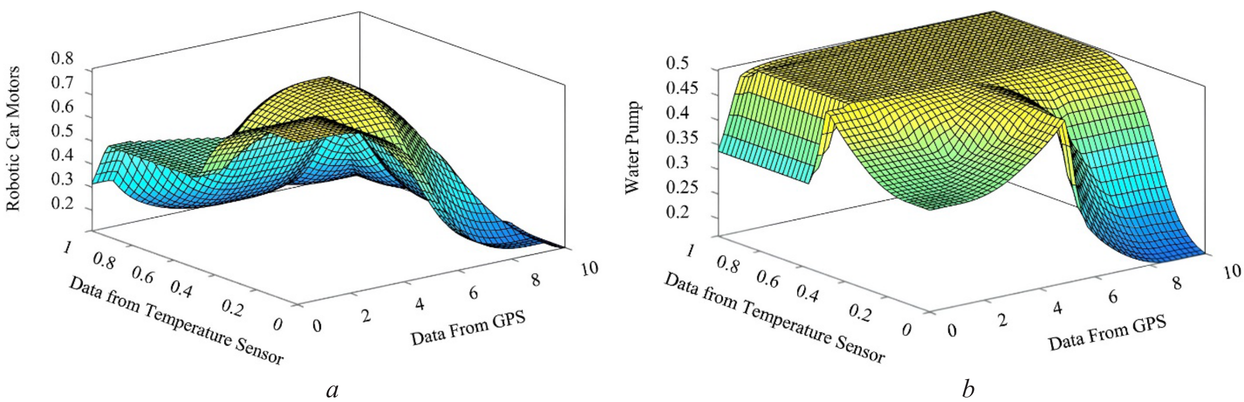

Fig. 9. Controller performance:
a – motors behavior based on data from GPS and Temperature sensor; *b* – water pump behavior based on data from temperature sensor and GPS

The proposed algorithm has been practiced for several cases and different data based on the fire scenario to show the algorithm response rate with two fire extinguisher tools as represented in **Fig. 11**.

As the variation in terms of probability of fire extinguisher using either water Pump or Foam Pump for fire extinguishing have been illustrated in the above figure and the proposed algorithm decided which tool of fire extinguisher is assigned based on trained data and trained scenario using Fuzzy logic controller which the system has been build. In the event that the data obtained from the flam and temperature sensors were close, the proposed algorithm can identify which tools is appropriate.

This will produce a fit tool and increase the response of the fire fighter robot to deals with different fire scenarios. Also, the time response variation has been calculated as shown in **Fig. 12**.

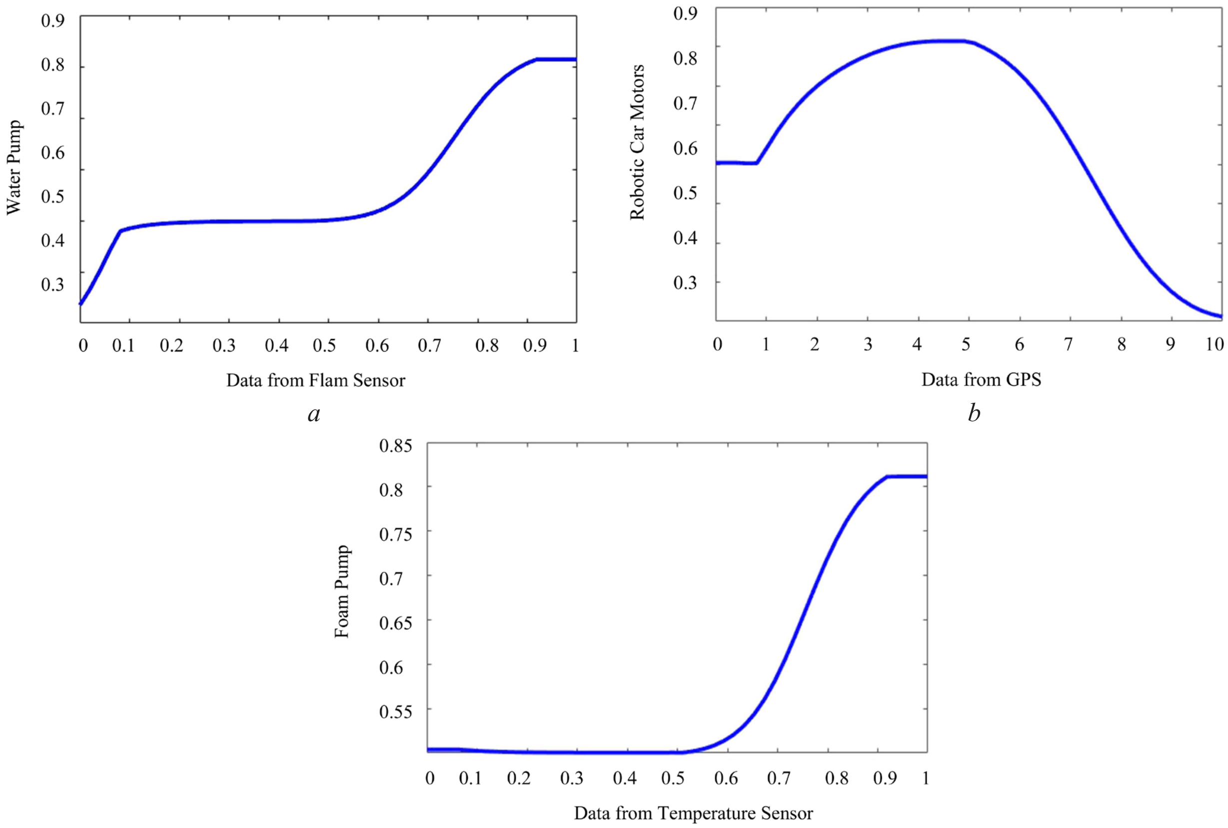

Fig. 10. Overall output performance:
a – water pump performance based on flam sensor data; *b* – foam pump performance based on temperature sensor; *c* – motor performance based on GPS data

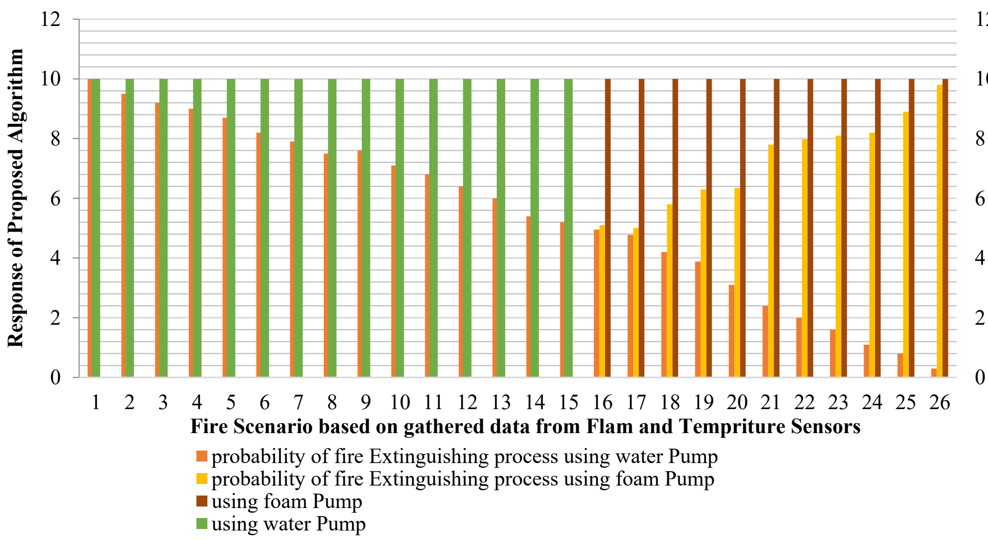

Fig. 11. System validation based on the probability of Fire scenario

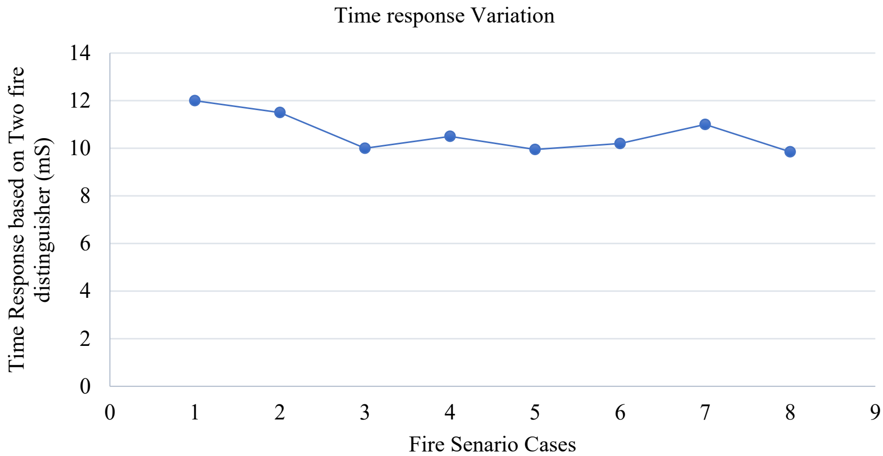

Fig. 12. Time variation response

By using the appropriate tools of fire extinguishing, it shows that the two scenarios have the same or close time response based on the gathered data either from Temperature sensor or Flam sensor.

Since the system reaction has been tested using the aforementioned data, a conclusion about the system's applicability may be made using the actual data. The system's limitations are considered based on its size, as it comprises two types of fire extinguishing tools: foam pumps and water pumps. These factors contribute to the system's large size which considered as a limitation of this system I it's current condition. It can be utilized based on its present situation inside large area premises.Moreover, the system can be further enhanced in terms of system structure to have the capacity to travel inside the constricted area as well as climb stairs.

This system can be upgraded, by applying the suggested algorithm, more sensors and different types of fire extinguishing tools which can be involved, creating a robotic fireman car that can put out any kind of fire.

4. Conclusions

The design and development of a robotic autonomous firefighting vehicle has been completed successfully. This system may be utilized to put out fires, be deployed in various locations, and handle fire situations inside of buildings. The algorithm's development and programming with this system have demonstrated that it is essential for handling fire extinguishing situations. A suitable response in terms of utilizing the appropriate tool for firefighting has been observed and a flawless response has been recorded despite the data meddling (temperature and flame sensor gathered data) as the algorithm has been trained to identify the suitable tool. Foam and Water pump response based on the data of flam and temperature were accurate as the data are close and this algorithm takes into consideration the position of the fire based on robotic position. Such system can be applied to deal in the application where the data are close and suitable action needs be accomplished. This system can make the benefit of reducing the overall required time to deal with the situation of fire as this system is trained and make into consideration the all probabilities.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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