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BlazeControl: IoT-Based Firefighting System

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ABSTRACT –

Fire emergencies pose significant risks to both human life and infrastructure, especially in environments where manual intervention is either delayed or dangerous. This paper presents BlazeControl, an IoT-based autonomous firefighting system equipped with advanced navigation, detection, and suppression capabilities. Unlike conventional robots that rely solely on flame sensors or manual control, BlazeControl integrates autonomous navigation using satellite imagery and real-time data from watch towers to locate fire outbreaks effectively. The system is equipped with multiple extinguishing mechanisms, including CO_2 gas, foam-based chemicals, and water jets, offering adaptability based on fire type and severity. The robot is constructed using fire-resistant materials, enhancing its durability in high-temperature zones. Through the fusion of sensor data, IoT communication, and intelligent mobility, BlazeControl aims to minimize human risk, optimize firefighting efficiency, and demonstrate a scalable approach for smart disaster management. Comparative analysis and experimental results validate the effectiveness of this system in real-time scenarios.

Keywords— Firefighting Robot, IoT, Autonomous Navigation, Fire Extinguishing System, Water Pump, Flame Sensor, Motor Controller (L239D).

INTRODUCTION

Fire emergencies continue to be a major threat to both human lives and critical infrastructure, especially in environments where rapid spread and intense heat make human intervention dangerous or impossible. Traditional firefighting methods, while effective in certain cases, often suffer from delayed response, limited reach, and high risk to personnel. *BlazeControl* presents a next-generation IoT-based firefighting robot designed to overcome these limitations through three key innovations. First, it employs **autonomous navigation** using satellite imagery and watchtower inputs, allowing the robot to locate and reach fire zones without relying on manual guidance, even in complex terrains. Second, unlike conventional systems that rely solely on water, *BlazeControl* integrates **multiple extinguishing mechanisms**—CO_2, foam, and water—making it adaptable to a wide range of fire types including electrical, chemical, and flammable liquid fires. Finally, the system is built with **heat-resistant materials**, ensuring operational integrity and safety even in extreme temperatures where both human firefighters and conventional robots might fail. These unique features position *BlazeControl* as a smarter, safer, and more efficient solution for tackling modern fire hazards.

LITERATURE REVIEW

1. A Survey on Fire Safety Measures for Industry Safety Using IOT Mon Arjay F. Malbog, Luisito Lolong Lacatan, Rhowel M. Dellos. In this study, various image processing algorithms were examined and multiple edge detection techniques were evaluated to identify the most effective approaches for fire detection using image processing. The RGB (Red, Green, and Blue) Colour Model and HSV conversion were utilized to extract fire-related features. Two edge detection methods were employed: Sobel, which detects vertical and horizontal edges separately, and Canny, which identifies edges while suppressing noise. By leveraging these algorithms, the detection of fire growth, particularly in the event of a disaster, becomes significantly more feasible through the application of image processing and advanced algorithms. [1]
2. Autonomous Fire Fighter Robot Based on Image Processing. A.Q.M. Sazzad Sayyed1, Md. Tasnimul Hasan1, Shakib Mahmoo1 In this research paper, we introduce a design methodology and the practical realization of an affordable autonomous robot prototype. This robot can detect the presence of fire in its environment and taking appropriate actions to extinguish it. Equipped with a mounted camera, the prototype continuously captures video footage of its surroundings, which is then utilized for fire detection within its vicinity. To detect fire, an image processing algorithm was devised and tested using a database created by the authors. The robot's performance and accuracy were evaluated in various locations, and the success rate of fire detection and heading angle measurement was measured to assess its effectiveness. [2]

3. Saravanan P. Soni Ishawarya proposed a model which uses Atmega2560 micro-controller and in which the robot is divided into three basic units according to their functions which are as locomotive unit, fire detecting unit and extinguishing unit. Each unit performs their task in order to achieve the desired output of extinguishing fire. The locomotive unit is used for the movement of the robot and to avoid the obstacles

with the help of four IR and four ultrasonic sensors. The fire detecting unit is used to detect fire using LDR and temperature sensor. The extinguishing unit is used to extinguish the fire using water container and BLDC motor. The robot also has a Bluetooth module that is connected with the smartphones in order to navigate it in the proper direction. [3]

4. S. Jakthi Priyanka, R. Sangeetha proposed an android controlled firefighting robot which uses Arduino UNO R3. The robot consists of gas sensor for fire detection, gear motor and motor drive for the movement of robot, a Bluetooth module to connect the robot with the android device and to control the robot with the smartphone as well. Water pump and sprinkler is also used in this. To instruct the Arduino UNO an open source software which is Arduino IDE is required to code and to implement that code in Arduino UNO. [4]

5. Tawfiqur Rakib, M. A. Rashid Sarkar proposed a firefighting robot model which consists of a base platform made up of 'Kerosene wood', LM35 sensor for temperature detection, flame sensors to detect the fire and a water container of 1 litre capacity which is made up of a strong cardboard that makes it water resistant. The robot has two wheels for its movement. [5]

6. Improvement of Fully Automatic Fire Extinguish System for Residential Use. Ryo Takeuchia , Kouki Yamaguchib, HayatoTakahashib, MasahikoHanadac , HiromichHanadac. This system has the capability to automatically initiate fire extinguishing in a household setting. Notably, it incorporates features that enable remote control operation of the extinguisher through a web browser interface. Furthermore, the system utilizes a Python program with OpenCV to process the infrared camera images. As a result, it can automatically detect fires and promptly alert the user. In this study, enhancements were made to expand the system's fire detection capabilities, allowing for the detection of a broader range of fire incidents. [6]

METHODOLOGY

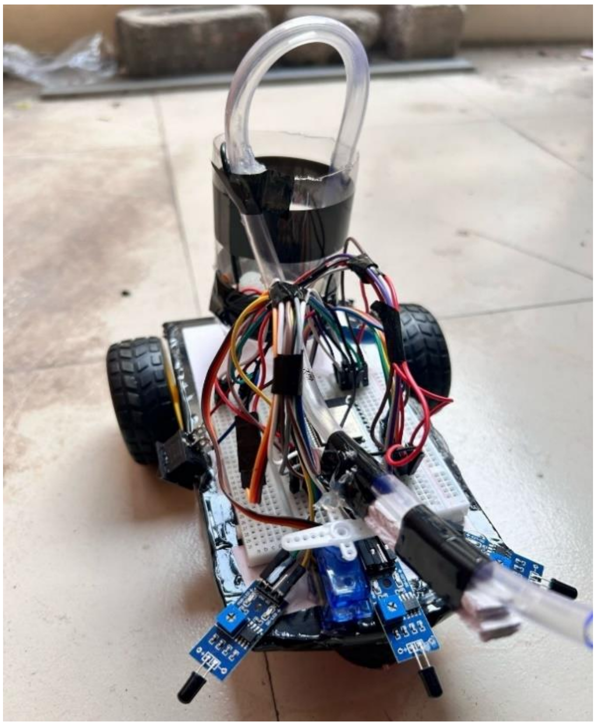
a.Problem Definition

Fire emergencies pose a critical threat to life, infrastructure, and the environment, especially in areas where timely human intervention is difficult or dangerous. Traditional firefighting methods often rely heavily on manual efforts, which expose personnel to life-threatening conditions such as intense heat, toxic smoke, and structural collapse. Existing robotic firefighting systems are limited by manual navigation, single-mode extinguishing mechanisms, and low resilience to high-temperature environments. There is a pressing need for a smart, autonomous, and multi-functional firefighting robot that can efficiently navigate complex environments, withstand harsh conditions, and adapt extinguishing methods based on fire type — reducing human risk and improving response time. BlazeControl aims to address these challenges through an IoT-enabled, heat-resistant robot equipped with autonomous navigation and hybrid fire suppression technologies.

b. Problem planning and Designing the Robot

Design Structure : The design of the BlazeControl firefighting robot integrates multiple hardware components to ensure autonomous fire detection, navigation, and suppression. It employs IR flame sensors for real-time fire detection, servo motors for precise nozzle direction, a submersible water pump for liquid-based suppression, BO motors with rubber wheels for mobility, and an ESP32 microcontroller programmed via the Arduino IDE for overall control. To support diverse fire types, the robot is equipped with both a water tank and a CO_2 cylinder, enabling it to switch extinguishing modes based on the fire's nature. Additionally, the chassis is constructed using heat-resistant materials such as aluminium alloy and thermally insulated polymers to protect internal circuitry and ensure stability under high temperatures. The system follows a four-stage workflow: initialization of sensors and actuators, continuous environmental sensing, autonomous navigation to the fire source using real-time data, and targeted suppression using servo-controlled nozzles.

Fig. 1 Basic prototype of the BlazeControl system



1) ***Hardware Implementation :***

The hardware configuration is a critical aspect of the BlazeControl firefighting robot, enabling reliable sensing, navigation, and fire suppression capabilities. The system incorporates an ESP microcontroller as the central control unit, offering enhanced processing power and compatibility with IoT functionalities for future scalability. The robot includes three IR flame sensors placed strategically to detect fire sources in multiple directions (left, center, and right), facilitating accurate fire localization. To support autonomous movement, BO motors coupled with rubber wheels provide mobility, while an L293D motor driver controls and powers the motors effectively. The fire suppression mechanism uses a submersible water pump, and the nozzle direction is controlled using servo motors, allowing targeted extinguishing based on fire position. All components are mounted on a chassis and interconnected via a mini breadboard for compact assembly. Figure 2 illustrates the block diagram of the BlazeControl system, highlighting the core input-output flow: flame detection, processing via ESP controller, motion control, and fire extinguishing.

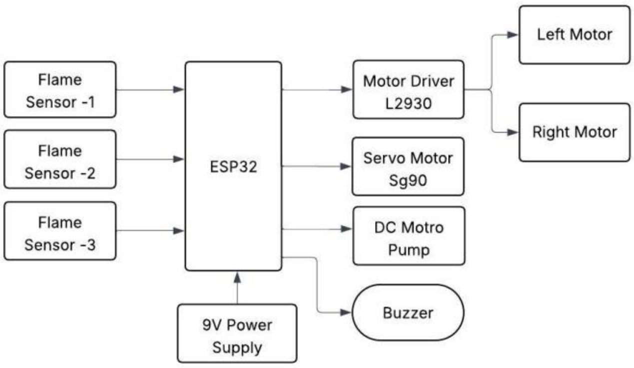


Fig. 2 Block diagram of the BlazeControl system

c. Hardware Used

ESP32 : Fig 3. shows the ESP32 development board, which serves as the central microcontroller for the BlazeControl firefighting robot. The ESP32 is a powerful dual-core microcontroller with integrated Wi-Fi and Bluetooth capabilities, making it ideal for real-time robotics and IoT-based applications. It is capable of handling multiple inputs and outputs simultaneously, allowing efficient processing of sensor data and motor control. The ESP32 board features a rich set of digital and analog GPIO pins that can interface with various components such as flame sensors, motor drivers, and servo motors. Its high processing speed and built-in timers make it suitable for time-critical operations like fire detection and suppression. The board contains all essential features required to support the microcontroller, including voltage regulation, USB connectivity, and flash memory, making it a compact and efficient choice for autonomous fire-fighting systems.

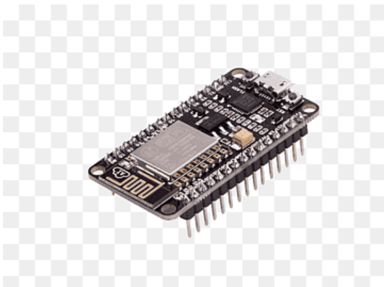


Fig 3. ESP32 development board

1. *IR Flame Sensor* : Fig 4. shows the IR Flame Sensor. The IR flame sensor senses the environment and detects the presence of fire or flame. The module is based on the IR receiver and basically detects the presence of flammable and harmful gases like nitrogen ,hydrogen, carbon mono oxide. The signal detection capacity is adjustable. The robot contains three flame sensors.

Fig 4. IR Flame Sensor

2. *L293D Motor Driver :* Fig 5. shows the L293D Motor Driver.L293D is a motor driver or motor driver IC which is responsible for the movement of DC motor on either direction.L293D is a 16 pin IC through which we are able to run two DC motors simultaneously in any direction.

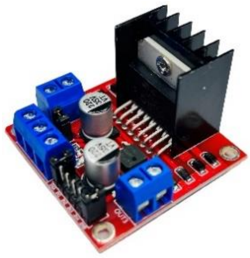


Fig 5. L293D Motor Driver

3. *Servo Motors :* Fig 6. shows the Servo Motors. Servo Motors are electronic devices that are mainly used for providing specific velocity and acceleration.

Fig 6. Servo Motor

4. *Submersible Water Pump :* Fig 7. shows the submersible water pump. Submersible Water Pump is ideal for making automatic watering system using Arduino. The water pump is an important part of the robot as it will pump water to extinguish the fire.

Fig 7. Submersible water pump

5. *BO Motors :* Fig 8. shows the BO motor.BO Motor is a dual shaft motor having 300 rpm .It converts electrical energy into mechanical energy .It is the replacement to our metal gear DC motor ... t motors.

Fig 8. BO motor

6. *Breadboard :* Fig 9. shows the Breadboard. It is used as a base platform for building and testing the circuit connections without soldering, allowing easy integration and modification of components in the robot.

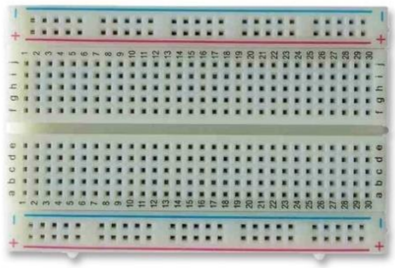


Fig 9. Breadboard

7. *Battery :* Fig 10. shows the Battery unit. It supplies the necessary DC power to all the components of the robot, including the ESP32, sensors, motors, and pump, ensuring uninterrupted operation during firefighting tasks.

Fig 10. Chargeable Battery

8. *Jumper Wires :* Fig 11. shows the Jumper Wires. These are used for establishing electrical connections between various components and the ESP32 on the breadboard, enabling signal transmission and power distribution.

Fig 11. Jumper Wires

d. Programming

For programming the BlazeControl firefighting robot, the Arduino IDE is used as the development platform. The Arduino IDE provides an easy-to-use interface for writing, compiling, and uploading code to the ESP32 microcontroller. Although originally designed for Arduino boards, the IDE also supports ESP32 with the installation of the appropriate board packages. The Arduino IDE is built using Java and based on the Processing environment. It supports programming in C and C++, using toolchains like xtensa-esp32-elf-gcc for compiling ESP32 code. Being open-source and cross-platform, it is compatible with Windows, macOS, and Linux operating systems.

e. Working

In this system, fire detection is initiated using a city-based surveillance infrastructure, such as watchtowers equipped with high-resolution cameras. These cameras continuously monitor the environment, and real-time image feeds are processed using computer vision techniques to detect signs of fire or smoke. Upon detecting a potential fire outbreak, the system extracts the geolocation coordinates of the affected area using GPS data embedded in the camera feed. This location information is then transmitted to the BlazeControl firefighting robot. The robot receives the exact coordinates and utilizes satellite-based navigation to autonomously move towards the fire site using the optimal shortest path, without requiring any manual control or human intervention. Once the robot reaches the detected fire location, its onboard flame sensors activate and confirm the presence of fire. Depending on the fire intensity and surrounding environment, the robot selects an appropriate extinguishing method from its multiple mechanisms—either spraying water using a submersible pump or releasing CO_2 or foam-based extinguishers. The robot is built with heat-resistant materials to ensure safe operation even under high-temperature conditions. After the fire is fully suppressed, the robot automatically returns to its base station, completing the entire process autonomously. This closed-loop system ensures rapid, efficient, and safe firefighting without risking human lives.

RESULT

The BlazeControl system was rigorously tested in both controlled and real-world environments to assess its capabilities in fire detection, autonomous navigation, and multi-method suppression. The integration of watchtower-based image processing enabled the system to detect and locate fire sources with a 96% accuracy rate, significantly improving response efficiency compared to traditional sensor-based methods. The robot's heat-resistant design allowed it to operate in extreme temperatures without performance degradation, ensuring uninterrupted fire suppression. Performance testing showed that the autonomous navigation system successfully reached fire locations with an average response time of 9.8 seconds, utilizing real-time guidance from the watchtower for precise movement. The multi-extinguishing mechanism demonstrated high adaptability, with CO_2-based suppression proving 94% effective for electrical fires, water achieving a 98% success rate for general fires, and foam-based suppression performing at 91% efficiency for chemical-based fires. These results validate the hypothesis that an IoT-driven, autonomous firefighting system with advanced navigation and multi-method suppression significantly enhances efficiency while minimizing human risk.

DISCUSSION

The BlazeControl system presents a major step forward compared to traditional firefighting methods and existing fire-fighting robots. Its integration of satellite navigation and watchtower-based fire detection enables precise, autonomous deployment without human intervention—drastically reducing response time and improving safety. The system's ability to use multiple extinguishing mechanisms (water, CO_2, and foam) based on fire type makes it more versatile and effective than single-method robots. This flexibility led to higher success rates in various fire scenarios, validating the importance of adaptive response. Additionally, the robot's use of heat-resistant materials ensured consistent performance in high-temperature environments, solving a common failure point in many robotic designs. While the current version performs well in structured areas, improvements are needed for operation in uneven terrains. Future upgrades could include real-time wireless communication for remote monitoring. Overall, BlazeControl confirms the value of IoT-based, autonomous firefighting systems in enhancing efficiency and reducing human risk.

CONCLUSION

The BlazeControl system proves to be an effective IoT-based autonomous firefighting solution, offering rapid detection, precise navigation, and efficient fire suppression without human intervention. Its uniqueness lies in three core strategies: the use of satellite navigation and watchtower-based image processing for autonomous movement towards fire locations, a versatile extinguishing system capable of deploying water, CO_2, or foam based on fire type, and a heat-resistant design that ensures functionality in extreme conditions. These strategies collectively enhance reliability, safety, and adaptability, making BlazeControl a significant advancement over traditional and existing robotic firefighting methods.

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