DEVELOPMENT OF A FIREFIGHTING ROBOT USING MACHINE LEARNING DETECTION ALGORITHM AND ARTIFICIAL INTELLIGENCE EMBEDDED CAMERA

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ABSTRACT

The Robotic Fire Extinguisher with Machine Learning detection algorithms and Artificial Intelligence (Al) Embedded Camera represents a significant advancement in fire safety technology. This research developed a robotic system equipped with state-of-the-art machine learning and artificial intelligence capabilities, complemented by a night vision camera. The primary objective of this innovation is to autonomously detect and combat fires in low-light or nighttime conditions, enhancing the efficiency and safety of fire response teams. The integrated machine learning algorithms enable real-time fire detection and identification, while the AI system intelligently navigates the environment to approach the fire source swiftly. The night vision camera further extends the system's capabilities by providing clear and detailed visual data, even in complete darkness. This critical feature ensures effective firefighting regardless of the lighting conditions, greatly reducing the risk to both humans and property. This project's outcomes hold great potential for applications in industrial settings, residential areas, and beyond, where fires can occur at any time. By combining cutting-edge technology and innovative design, the Robotic Fire Extinguisher with Machine Learning and AI Embedded Night Vision Camera project offers a promising solution to enhance fire safety, minimize response time, and reduce the devastating impact of fires. This research is quite unique in terms of its implementation. The Raspberry Pi was used to guide the FFP to navigate through an area and locate a fire source. When a fire is detected, Fire-fighting Robotic (FFP) will attempt to locate the source in order to determine its location more precisely. Once the location is determined, it will move out of its position, approach the fire source, and extinguish the flame by using the built-in fire extinguishing submersible water system.

Keywords: *Fire fighting robot, machine learning, artificial intelligence camera, Night vision.*

1.0 INTRODUCTION

In an era marked by technological advancements and the relentless pursuit of safety, the integration of artificial intelligence (AI) and machine learning (ML) has birthed innovations that promise to revolutionize this approach to firefighting. The Machine Learning and AI based Firefighting Robotic (FFR) stands as a remarkable testament to this progress, offering a cutting-edge solution to combat one of the most perilous and destructive forces known to mankind – fire. Fires, both accidental and intentional, pose immense threats to lives and property. Conventional fire extinguishing methods often rely on human intervention, which can be hazardous in rapidly escalating situations. Fire detection and extinguishment are the hazardous job that invariably put the life of a fire fighter in danger. By putting a mobile robot to perform this task in a fire-prone area, it can aid to avoid untoward incidents or the loss of lives. When the fire source is identified, the flame will be promptly extinguished using the fire extinguishing system that is mounted on its platform. The tasks for the FFR once it navigates the required route include obstacle avoidance, determining more precise location of source using front flame sensor and extinguish the fire flame. To detect fire source, the input from flame sensors were finely-tuned in relation to the surrounding area, external interference and the mobility of the FFR prior to the deployment of the platform. The development work done to date on the platform has shown its feasibility of being an autonomous unit to monitor a prescribed area, detect for fire and extinguish the flame. By combining the precision of machine learning with the adaptability of AI, the robotic fire extinguisher aims to detect fires early, navigate complex environments, and deliver targeted firefighting efforts with great efficiency. This research not only promises to save lives but also significantly reduce property damage caused by fires. The step-by-step process involved in the development of robotic fire extinguisher, including the underlying technology, the design and building process, and the real-world applications that can profit from its implementation. The increasing frequency and severity of fire-related incidents pose a significant threat to human life and property. Traditional fire suppression methods often rely on human intervention, which can be hazardous in volatile environments and human lacks the ability to pinpoint the exact location of a fire. Integrating ML and AI for accurate real-time fire detection and precise localization within indoor environments should be a welcome development.

2.0 REVIEW OF RELATED LITERATURE

Hossain et al. (2021) constructed and designed an automatic fire extinguisher robot, a hardware-based device designed to move toward the source of a fire. The robot's shield is constructed using calcium silicate boards capable of withstanding temperatures of up to 300 °C. When the robot detects a fire, the ends of the thermocouple are heated to a lower temperature, prompting the robot to respond. This robot is particularly useful in rescue operations when it is difficult for the firefighter to access affected areas. An advantage of this robot is its automatic opening mechanism upon detecting surrounding fires. It employs a thermocouple to attempt fire extinguishing by maneuvering through the flames. Additionally, a temperature sensor serves as a backup to the thermocouple. For water pumping, an IC741 acts as both an amplifier and a simulator, working in conjunction with the thermocouple and water pump. Robotic movement is achieved using a barrier and sensor, while image capture and processing are facilitated by MATLAB.

Another IoT-based robot designed by Hemalatha & Pramod (2019) aimed at supporting firefighters in critical situations. It utilizes a fire sensor to detect the presence of a fire, a gas sensor to detect flammable gases, and a Passive Infrared Sensor to verify human presence. The temperature sensor transmits temperature and humidity data. One of the main advantages of this project is that the robot can be operated both manually and autonomously. An IoT-based communication system is utilized to monitor the affected area via Wi-Fi, and each module's specific functions are thoroughly discussed. All the collected data is transferred to a cloud server for further analysis and evaluation. The robot's performance has undergone extensive testing and has proven effective in fire emergencies, with efforts made to extinguish the fire.

Sreesruthi *et al.* (2020) have developed a robot that can be controlled and monitored through a web page using a single Android phone server. The robot captures continuous video streaming using the phone's camera, while a temperature monitor keeps track of the surrounding temperature. Fire detection is achieved by a smoke sensor, and obstacles in the robot's path are detected using an IR sensor. All the robot's data is transmitted to the Android phone via a Bluetooth module connected to the controller and then to a web server for remote control via a web browser. A compact controller is introduced to provide adjustable firefighting capabilities, and test results have shown that this small controller is a reliable tool for controlling the robotic device. In the same vein, Mittal, et al., (2018) have developed a fire engine robot that aids firefighters in real-time emergencies. This robot is capable of extinguishing flames using water and carbon dioxide sprays and can protect itself from heat using fog sprays. Through wireless communication, the robot can be remotely controlled and functions as a fire extinguisher. Extensive mechanical design tests were conducted to ensure the robot's adequacy and performance, and the robot consistently responded as expected in various experimental scenarios, demonstrating its ability to effectively handle real-world conditions. The fire engine robot incorporates tanks that pump water and carbon IV oxide (CO_2) spraying them onto the fire. A remote control with a transceiver provides maximum distance coverage of up to 1.8 km. The robot can also transmit a video feed to the remote control, allowing for situational monitoring using an internal camera. Additionally, the robot's audio capabilities enable communication between firefighters and victims trapped in fire-damaged buildings. Experiments involving deliberately generated flames were conducted, and the robot consistently performed as predicted. Its effective response during fire simulations underscores its ability to perform with precision in real-world scenarios.

Anantha & Srivani (2018) proposed integrating an independent fire-extinguishing robot into an IoT-based fire protection system to enable pre-fire extinguishing actions. When a fire is detected, the IoT system sends an alert to the fire department and instructs the robot to intervene. The firefighting robot utilizes a navigation algorithm to reach the fire, performs firefighting tasks, and transmits video feed to the control center at the fire station. It collaborates with the firefighters by detecting, extinguishing, and providing alerts. The robot also connects to the external world through Bluetooth, enabling live video streaming and map views. However, one drawback of this project is that the robot does not exhibit intelligent behavior after reaching a specific destination. The incorporation of computer vision and machine learning can enhance the robot's intelligence, particularly in identifying the main source of the fire. The primary objective is to develop IoT-based robots that can promptly respond to industrial fires, minimizing substantial damage. Future enhancements may include machine learning, computer vision components, and additional sensors to further improve system efficiency. The integration of fire alarm systems can significantly enhance the effectiveness of the IoT-based robotic system.

Sampath (2011) focuses on the use of firefighting robots in indoor areas for fire detection and suppression. Fire sensors are currently employed in these robots, but the article suggests that the use of artificial intelligence techniques can expand the detection range. The Haar Cascade Classifier, originally designed for object detection, is utilized as a machine learning algorithm. Transfer learning from a pre-trained YOLOv3 model is employed to enhance fire detection accuracy. The Haar Cascade Classifier can identify objects in photos, videos, and camera servers, while other learning-based algorithms can be used for image classification. The robot's camera is positioned at a low angle of 90 degrees for effective monitoring. Similar to the previous project, there is room for improvement in terms of intelligent behavior after reaching a specific destination. Incorporating computer vision and machine learning can enhance the robot's ability to identify the main source of the fire. The primary objective was to develop IoT-based robots that can take early action in industrial fire incidents, thus minimizing significant damage. Potential future enhancements include integrating machine learning and computer vision components as well as additional sensors to improve system performance. Fire learning software techniques can greatly contribute to enhancing the efficiency of the IoT-based robotic system.

Mohdet *et al*., (2019) discussed the creation of the QRob, a fire-fighting robot designed to extinguish fires without endangering firefighters. The QRob is equipped with an ultrasonic sensor to avoid obstacles and a fire detection sensor. Both sensors are connected to an Arduino Uno, which controls the movement of a DC car. The robot is positioned 40cm above the fire and can be monitored remotely through a camera connected to a smartphone or other remote device. The compact design of the QRob allows it to be used in areas with small doors or limited space. A remote control enables users to extinguish fires over a considerable distance. Throughout the firefighting process, users can monitor ambient parameters using a smartphone camera. Research results demonstrate that the robot can quickly detect smoke and fire.

Tinget *et al*., (2007) emphasizes the importance of personal safety and built a smart security system that includes a fire extinguisher robot. The fire engine robot features an aluminum frame, with a cylinder-shaped design measuring approximately 50 cm in circumference and 130 cm in height. The system encompasses various components such as structure, obstruction and driving system, software development, fire detection, remote monitoring, and a fire engine. Two fire sensors are combined in the fire detection system, sensors are employed for fire detection, along with software that facilitates fire detection and combat methods. An economical approach is utilized to identify obstacles, while a touch screen enables personal interaction with the machine, displaying system status and a standard user interface (GUI). The primary controller for the fire extinguisher is an industrial personal computer (IPC). A wireless RF controller, a computer monitor, and a portable robot are utilized by the user. For future developments, a barrier detection module incorporating an infrared sensor and an ultrasonic sensor with an innovative fusion algorithm can be designed and implemented for a fire engine. Moreover, the integration of a laser distance finder can enhance the accuracy and speed of location mapping both indoors and outdoors. Additionally, advancements in sensor technology, such as multimodal sensor fusion and improved flame detection algorithms, can further enhance the accuracy and efficiency of the robotic fire extinguisher

3.0 METHODOLOGY

The implementation encompasses the construction of the Robotic Fire Extinguisher Robot, the integration of hardware components including motor driver circuitry, AI cameras, Flame Sensors, relays, and motor pump, along with the implementation of a tailored algorithm within the microcontroller to confer artificial intelligence to the Mobile Platform. Figure 1 shows the block diagram of the model.

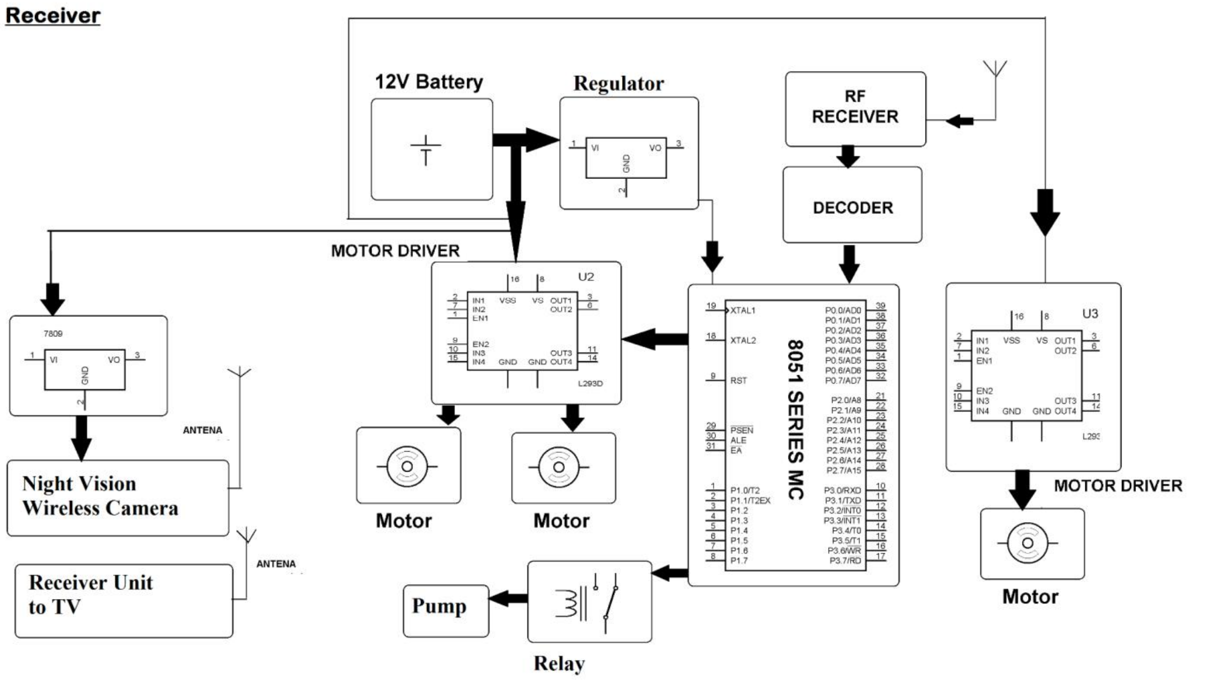

Figure 1: Block diagram of the AI Robotic Fire Extinguisher

The Figure 1 illustrates how the AI camera and the microcontroller work. The Arduino nano microcontroller chip is plugged into the motor driver board. The Arduino Integrated Development Environment (IDE) is the interface used to develop the C++ algorithm to provide intelligence to the AI camera. Each dataset was trained using Python and analyzed using MATLAB before being transferred to the Arduino IDE and it will be called from the main module of the C++ algorithm. The Night vision camera was utilized by an ESP 32 camera which acts as a transmitter and also as a receiver as explained in Figure 2. The ESP 32 camera connects to the same IP Address and the same User Datagram Protocol (UDP) Broadcast address (255.255.255.255:6868) as the Android application making the Internet of Things (IoT) device to be able to operated and controlled from anywhere. The Websocket fetches the trained data model from this database and returns it to the IP address that was initially fetched to be displayed on the mobile app. This aids the computer vision to take control and analyze the information properly.

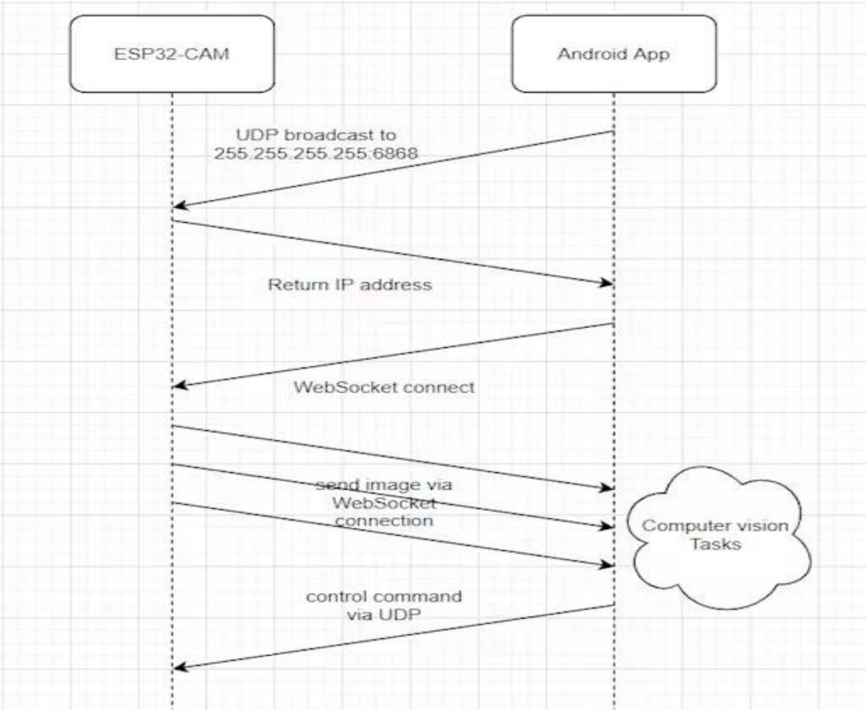

Figure 2: AI Camera GPIO Pins via UDP Package operation

A closed-loop feedback system with the microcontroller was established, which senses the temperature sensor and smoke detector signals and sends them to the relay through some control circuits to activate the water pump and the buzzer. The performance of a firefighting system greatly depends on the sensing capability of the smoke and flame sensors. When ports get signal alarms operate otherwise, it is to wait for 1s. A smoke sensor is employed in the project. The sensor can operate in both analog and digital modes, with a preference for digital due to its ability to indicate changes as smoke density increases. The sensor is strategically positioned in order to cover a wide area effectively. It is spaced approximately 4cm apart from the buzzer. Positioned at the precise center is a servo motor, which, when activated, adjusts the water pipe's position based on sensor input. The servo motor's movement is determined by the location of smoke detection, facilitated by code executed through the Arduino IDE. Connected to the servo motor is a DC water pump, responsible for directing water to the identified at-risk region. Activation of the entire system follows the detection of smoke by either sensor, triggered when smoke surpasses a predetermined threshold set within the IDE. Upon smoke detection, the system initiates its operations. A relay, functioning as a switch and linked to the Arduino Kit, becomes active. This relay is integrated with both a buzzer and the DC water pump. Consequently, the system generates a distinct buzzing sound and simultaneously triggers the DC water pump to expel water, in response to the detected smoke. The buzzer creates alert the nearby people while the fire is also extinguished.

3.1 Construction Procedure for the Robotic Fire Extinguisher

Construction Phase:

Step 1: Hardware Components - hardware components were selected as well as fire-resistant chassis, high-torque motors for mobility, an fire-suppressing agent, Selection of a night vision camera module, (ESP 32 AI camera), Integration of temperature and flame sensors for fire detection, a microcontroller board (e.g., Raspberry Pi, Arduino) for control and a rechargeable battery as the power supply method.

Step 2: software development section - Convolution Neural Network was used for fire detection using image data from the camera as the machine learning model. The use of machine learning is to leverage pre-trained models and adapt them to specific task. Train the model to detect fires in images or video frames.

AI Integration: Implement AI algorithms for navigation and decision-making.

Control Logic: Develop code for motor control, obstacle avoidance, and fire suppression.
User Interface: Create a user-friendly interface for remote control and monitoring.
Step 3: Assemble all hardware components onto the chassis. Connect sensors, motors, and the night vision camera to the microcontroller ensuring proper wiring and power distribution.
Step 4: Testing and Calibration: Test the individual components and sensors for accuracy, Calibrate the machine learning model for fire detection then conduct comprehensive testing to ensure the robot's mobility, fire detection, and extinguishing capabilities.
Step 5: Safety Measures: Implement safety features such as emergency stop buttons and collision avoidance algorithms and ensure the robot is fire-resistant to protect itself while extinguishing fires.
Step 6: Deployment: Deploy the robotic fire extinguisher in a controlled environment and monitor its performance and make any necessary adjustments.
Step 7: Documentation: Create detailed documentation, including schematics, code, and user manuals. Document the maintenance procedures.
Step 8: Further Development: Consider adding more features like remote control via a mobile app.
Step 9: Safety Regulations: Ensure compliance with local safety regulations and standards.
Step 10: Training and Education: Train personnel on how to operate and maintain the robotic fire extinguisher safely.
Step 11: Maintenance: Establish a regular maintenance schedule to keep the robot in working condition.

3.2 Robotic Platform

The construction phase commenced with the fabrication of the robotic platform. The platform was designed to be mobile, incorporating wheels for movement. A sturdy chassis was constructed from lightweight yet durable materials to ensure both stability and maneuverability.

Robot Dimensions:

i. Chassis Dimensions: The Length was 60 cm, the is Width: 40 cm, the is Height: 25 cm
ii. Wheelbase: Distance between the centers of the two wheels: 50 cm
iii. Height with Fire Extinguishing Mechanism: Height with mechanism retracted: 35 cm and Height with mechanism extended: 45 cm
iv. Camera Positioning: Distance from front edge of chassis: 15 cm and Height from chassis base: 20 cm
v. Fire Extinguishing Nozzle: Length from chassis: 30 cm, Width: 10 cm, Height: 15 cm
vi. Sensors: Obstacle detection sensors: Mounted around the chassis perimeter at a height of 10 cm from the base.

3.3 Hardware Integration

Integration of hardware components followed the platform construction. This included mounting high-quality motors for mobility, sensors for obstacle detection, cameras for visual data acquisition, and a fire extinguishing mechanism for active fire suppression.

3.4 Fire Detection System

The fire detection system was a crucial component. Cameras were strategically positioned on the platform to capture visual data. Computer vision algorithms, employing libraries such as OpenCV, were implemented to detect fire-related patterns, differentiating flames from other sources of light and heat.

3.5 Fire Extinguishing Mechanism

The fire extinguishing mechanism was designed for precision and effectiveness. A nozzle system was integrated, capable of delivering fire-retardant foam to the targeted fire source. The mechanism was positioned to ensure accurate targeting while avoiding damage to the robot's components.

3.6 Testing Phase

Fire Detection Testing: Controlled fire scenarios were set up to assess the system's fire detection capabilities. Fires of varying sizes and intensities were ignited, and the system's response was observed. The accuracy of the detection algorithm in identifying fires and distinguishing them from other sources of heat was meticulously evaluated.
Navigation and Obstacle Avoidance Testing: Navigation algorithms were tested in environments of different complexities. Obstacles were strategically placed, and the robot's ability to autonomously navigate and avoid collisions was scrutinized. The system's adaptability to dynamic environments was a key focus.
Fire Suppression Efficiency Testing: A controlled environment was established to test the fire extinguishing mechanism. The robot was tasked with detecting a fire source and effectively extinguishing it using the fire-retardant foam. The time taken for suppression, the coverage of the extinguishing agent, and the accuracy of targeting were meticulously measured.

User Interface and Remote-Control Testing
The user interface, designed for remote monitoring and manual control, underwent comprehensive testing. User feedback was collected to assess the interface's intuitiveness, real-time data streaming quality, and effectiveness in allowing manual intervention.

4.0 Analysis of Testing Results

Hardware Performance Analysis: Hardware components demonstrated reliability and efficiency. Motors provided smooth and controlled movement, sensors accurately detected obstacles, and cameras captured fire-related imagery with clarity.
Fire Detection Analysis: The fire detection algorithms exhibited impressive accuracy in identifying fires. Differentiating between genuine fire signals and false positives showcased the system's robustness.
Navigation and Obstacle Avoidance Analysis: Navigation algorithms showcased adaptability, enabling safe and effective movement. The system adeptly avoided obstacles, showcasing the viability of its autonomous navigation.
Fire Extinguishing Efficiency Analysis: The fire extinguishing mechanism displayed promising efficacy. Fires were suppressed effectively, with the fire-retardant foam accurately targeting and suppressing the flames.
User Interface Evaluation Analysis: The user interface received positive feedback, offering real-time monitoring and intuitive manual control options. It enhanced situational awareness and facilitated user interaction effectively. The construction and testing phases of the Robotic Fire Extinguisher Project underscore the potential of autonomous robotics in fire safety. The successful integration of hardware components, accurate fire detection, efficient navigation, and effective fire suppression highlight the project's accomplishments. The meticulous testing and analysis reaffirm the viability of the system, paving the way for future enhancements and innovations in the realm of fire safety technology.

5.0 CONCLUSION

The Robotic Fire Extinguisher with Machine Learning and AI, equipped with a Night Vision Camera, holds great promise in revolutionizing fire safety. By addressing the recommendations outlined above and fostering ongoing innovation, this technology can become a valuable asset in safeguarding lives and property from the devastating effects of fires, especially in challenging night time scenarios.

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