EMBER BOT

Jonathan Chen, Kevin Rivera, Nancy Ramirez Castillo, Yuwen Zheng

CONCEPT OF OPERATIONS

REVISION – Draft
5 February 2025

CONCEPT OF OPERATIONS
FOR
EMBER BOT

TEAM #30

APPROVED BY:

_____
Jonathan Chen 2/5/24

_____
Prof. Kalafatis 2/5/24

_____
Swarnabha Roy 2/5/24

Change Record

Rev.	Date	Originator	Approvals	Description
1	2/5/2024	Jonathan Chen		Draft Release

Table of Contents

List of Tables

No tables in this document.

List of Figures

1. Executive Summary

This project's purpose is to create a solution regarding the rising concerns of fires in dangerous or hard-to-reach locations where first responders would be unavailable. Ember Bot, a mobile-controlled fire-fighting vehicle, is an innovative solution designed to enhance the safety and efficiency of firefighters by addressing challenges posed by hazardous environments. This remotely operated robot uses wireless technology to enable real-time control, allowing it to perform tasks in areas too dangerous or inaccessible for human responders. Equipped with fire-extinguishing mechanisms and fire detection, the vehicle can combat fires in high-risk scenarios. Its compact and agile design enables it to navigate through narrow pathways, debris-filled areas, or uneven terrains, providing a versatile tool for emergency response. The onboard sensors and camera allow it to monitor environmental conditions and provide critical data to operators. By minimizing the exposure of human firefighters to extreme heat, toxic fumes, or unstable structures, the controlled fire-fighting vehicle significantly reduces the risk of injuries and fatalities. Its ability to operate remotely in life-threatening conditions makes it a valuable tool for disaster management and emergency response teams. Additionally, this design scope can be adapted and improved for varying first responder scenarios, from urban environments to industrial facilities.

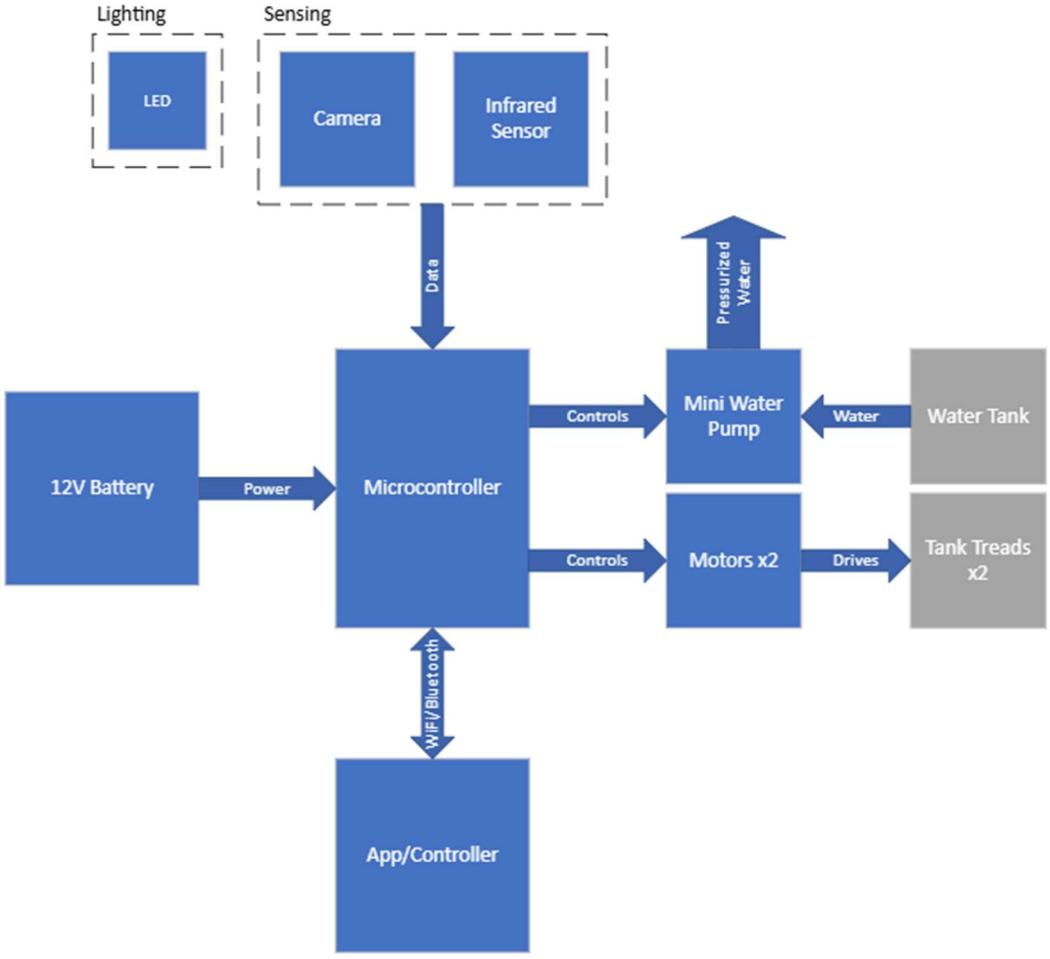

Figure 1. System Diagram of Ember Bot

2. Introduction

In fire emergencies, rapid response and safe intervention are critical. This document introduces Ember Bot, a firefighting robotic vehicle that aims to provide a remotely operated solution for firefighting in unfavorable environments. This robotic vehicle is designed to detect and extinguish fires while minimizing risks to human firefighters.

2.1. Background

Firefighting is a critical operation that often requires personnel to enter dangerous environments, exposing them to extreme heat, toxic smoke, and potential structural collapses. Traditional firefighting methods rely heavily on human intervention, with firefighters manually operating hoses and suppression systems to combat fires. However, these conventional approaches come with significant limitations, including restricted reach, possible loss of personnel, and potential delays in response time, especially in hazardous or hard-to-access locations.

Ember Bot is designed to serve as a versatile and efficient tool for fire suppression in a variety of environments. It can be deployed in residential, commercial, and industrial settings where fire hazards pose significant risks [1]. The ability to remotely control the vehicle makes it especially useful in non-traditional areas, where human intervention may be dangerous or impractical. Beyond emergency response, the system can also be integrated into fire prevention strategies, serving as a preemptive guard against fire-prone locations to detect and respond to potential hazards before they escalate. The adaptability of this robotic vehicle allows it to be customized for different situations, making it a valuable addition to firefighting teams, industrial safety protocols, and other operations.

A key component of our vehicle is introducing remote-controlled operation via a mobile application. This feature allows operators to navigate the robot toward fire-prone areas from a safe distance, ensuring that human exposure to extreme conditions is minimized. The use of Bluetooth and/or WIFI communication provides a stable and reliable control mechanism, unaffected by obstructions or interference that might compromise other wireless technologies in emergency scenarios, such as smoke and connection issues [2].

Additionally, other systems specifically designed include the mobility of our robotic vehicle via threads and the use of a pressurized pump for manual water dispersal. These systems allow it to access areas that may be difficult or dangerous for firefighters to reach. The combination of real-time maneuverability, remote operation, and a controlled suppression system makes our vehicle a valuable enhancement to existing firefighting infrastructure.

2.2. Overview

Ember Bot will consist of a mobile-controlled robotic platform vehicle equipped with fire suppression components. The system will integrate wireless communication, allowing the user to navigate the vehicle and activate the fire suppression mechanism through a mobile application. The robot will receive movement and operation commands through a mobile app, which will process the signals and control the vehicle's mobility and firefighting functions. The onboard pressurized pump will enable manual water dispersal, providing precise control over the firefighting process. Real-time data from the onboard infrared sensors can assist in identifying fire sources and optimizing suppression strategies. The system will improve fire response capabilities by allowing users to safely operate the vehicle from a distance, reducing risks associated with direct human intervention. Over time, the system's usage data and performance metrics can be analyzed to refine fire suppression techniques, improve operational efficiency, and inform future design enhancements. The diagram below illustrates the flow of control and communication within the system.

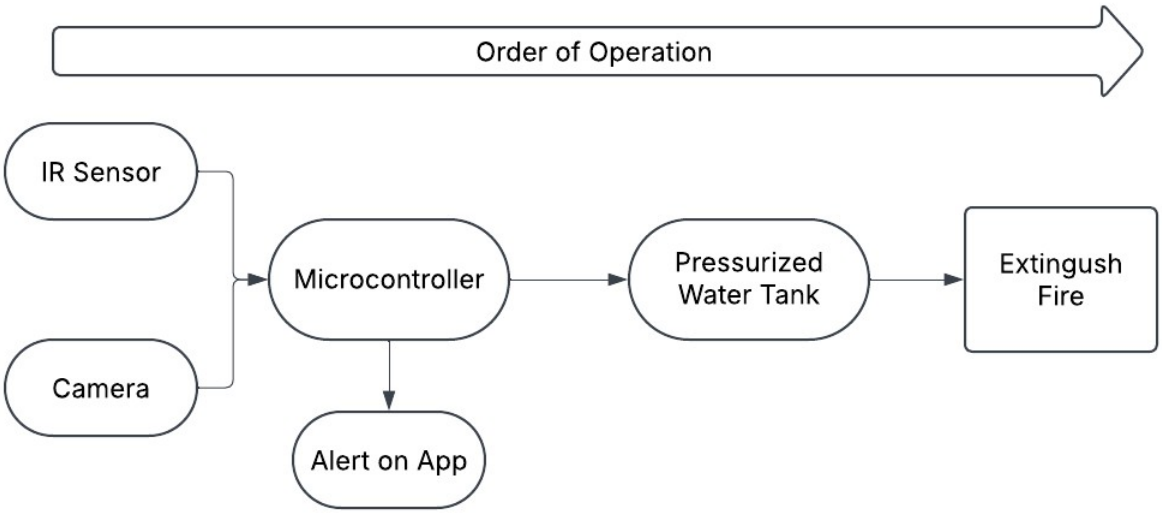

Figure 2. Order of Operation of Fire Suppression

Additional functionality may be considered depending on the goals of the vehicle.

2.3. Referenced Documents and Standards

[1] Lattimer, B. Y. (n.d.). "*Robotics in Firefighting"*. SFPE. https://www.sfpe.org/publications/fpemagazine/fpeextra/etarchives3/fpeetissue100

[2] "*Where there's smoke, there's a signal"*: Homeland Security. U.S. Department of Homeland Security. (n.d.). https://www.dhs.gov/archive/where-theres-smoke-theres-signal

3. Operating Concept

3.1. Scope

For the scope of this project, a list of subsystems is being designed that will be combined at the end so that the Fire Fighting Robotic Vehicle can function as needed to achieve our primary goals for this project. The exact subsystems for this project are as follows:

- Fire Detection Subsystem
- RC Car and Pump Subsystem
- Power for the Robotic Vehicle
- App and Controller for the Robotic Vehicle

Documentation for the design, calculation, programming, and construction of different subsystems will be provided for all parts of the project.

3.2. Operational Description and Constraints

Ember Bot will be used as an efficient tool for firefighters in different scenarios. If a fire is in areas that are too dangerous for firefighters to access, Ember Bot will be enabled and perform tasks in these dangerous areas. The vehicle can also be used when the space is too narrow for a firefighter to get into. It can be controlled with a real-time mobile app to put out fires in these high-risk areas. Scenarios of the possible usage of Ember Bot include but are not limited to:

- Burning buildings that are likely to collapse
- Buring industries with hazardous materials
- Tunnel fire
- Shipboard fire

Ember Bot is not designed to be used in regions where the controller is too far away from the fire or complex regions that will limit the movement of the Robotic Vehicle.

3.3. System Description

Ember Bot is combined with four subsystems including the Fire Detection Subsystem, RC Car and Pump Subsystem, Power for the Robotic Vehicle, and App Controller for the Robotic Vehicle. The components the four subsystems use are described below:

Microcontroller: The microcontroller serves as the central processing unit of Ember Bot where it will receive commands from the mobile application and control the motors, light source, IR sensors, camera, and pressurized pump accordingly. The microcontroller processes sensor data to assist in fire detection, pressure output, and navigation, ensuring smooth and efficient operation.

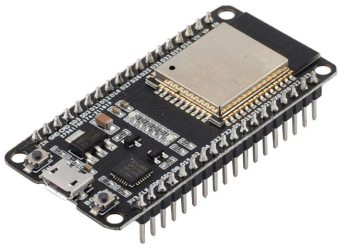

Figure 3. ESP-32 Microcontroller

IR Sensor: The Infrared Sensor is used for detecting fire and obstacles by sensing infrared radiation emitted from heat sources. It helps identify the presence of a fire by detecting temperature variations and can assist in guiding the robot toward the fire.

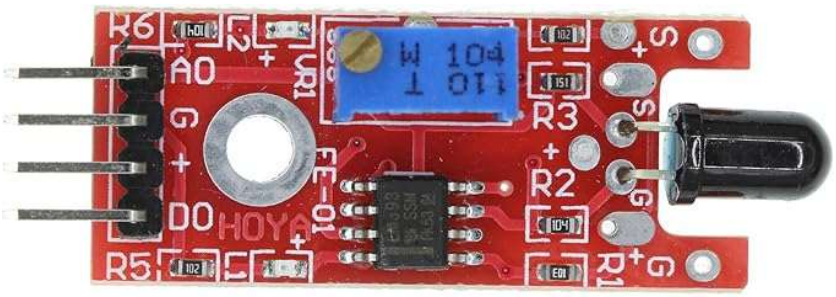

Figure 4. KY-026 IR Sensor

Camera: The camera module provides real-time visual feedback to the operator, enabling remote monitoring and precise control of the robot. The live video feed helps in navigating through hazardous areas and accurately aiming the fire suppression system. It also enhances situational awareness by allowing the operator to manually assess the fire's intensity and surroundings.

Figure 5. Camera Tool

Light Source: The light source is an essential component of Ember Bot, primarily used for visibility enhancement in low-light or smoke-filled environments. It helps the onboard camera capture clearer images for the operator, improving navigation and fire suppression accuracy.

Figure 6. 5V LED Light Source

RC Car and Pump: The RC Car itself is what will be holding all our robotic vehicles' components and the water tank. Tank treads with motors will be used for mobility in possibly rough terrain. The water tank will hold half a gallon of water and have a cap for it to be refilled. Electronics will also be isolated to ensure no damage during use. A water pump will be used to shoot pressurized water out of a nozzle to extinguish the fires. The nozzle will be able to be aimed at using servo motors to ensure accuracy in hitting its target.

Figure 7. Tank Tread Motor & Water Pump

Power: The entire system is powered by a 12V battery providing a reliable and efficient energy source for all components. The system will use a rechargeable battery to ensure continuous operation without the need for constant replacement and extra cost.

Figure 8. Rechargeable 12V 7A Battery

App and Controller: The mobile app is designed to fulfill all the needs of controlling the robotic vehicle for better task completion. The mobile app will provide real-time recordings for users to capture the fire. The user can control the robot to move around and put out the fire on this App. The app will be developed using the iOS system. The app will be programmed using Swift on Xcode.

3.4. Modes of Operations

Ember Bot shall use a primary mode of operation where the vehicle will provide real-time recordings of surrounding areas to users. The user can drive the robotic vehicle around until the fire is captured. Then the user can control the pump on the vehicle to put out the fire. The user can also simply tap on the location of the fire shown on the app. The robotic vehicle can aim automatically and put out the fire in that direction.

Ember Bot will also have warning notifications sent to the app when the battery is running low, or the robot is too far away from the user. Such notifications can lower the cost of maintenance of the robotic vehicle.

3.5. Users

Ember Bot is primarily designed as an efficient tool for firefighters when they have high-risk tasks or when they meet inaccessible areas. However, this robotic vehicle can also be used by adults of different ages due to its simple operation and affordable price.

3.6. Support

Manuals will be provided to users and there will also be instructions in the app so the user can access it immediately when needed. The manual will guide how to connect your phone to the robotic vehicle and how to operate the robotic vehicle. The manual will also include possible questions and answers about the robotic vehicle.

4. Scenario(s)

4.1. Assistance in Extinguishing Flames

Ember Bot will be able to assist firefighters in reaching hard-to-reach fires. Firefighters can deploy this robot to put out fires present behind tight openings or in hazardous areas such as areas with a risk of falling debris or potential explosions. Using a camera and infrared sensor, users can navigate the robot and use pressurized water stored in the robot to locate and extinguish the fire.

4.2. Search and Rescue

Using the built-in camera and wireless control, first responders can use Ember Bot to assist in Search and Rescue operations. The small size and tank tread wheels give operators the ability to go into hard-to-reach areas to find potentially trapped individuals. Operators can view the live stream on their phones and use an LED to light their way.

5. Analysis

5.1. Summary of Proposed Improvements

- Ember Bot will allow first responders to combat fires that source from narrow pathways, debris-filled areas, or uneven terrains minimizing human exposure to hazardous environments.
- By responding quickly to fires in inaccessible areas for first responders, the system can help prevent fire escalation and reduce property damage.
- Being equipped with cameras and sensors, the system provides live data and situational awareness to operators while the system is adaptable to various environments, and using wireless technology ensures stable control, even in conditions where other wireless signals may be disrupted.

5.2. Disadvantages and Limitations

- Since the robot is restricted by wireless communication range, this means that it cannot be in scenarios that are too far from the operator.
- Although we will be using tank treads to facilitate movement compared to standard wheels, complex terrains or heavily obstructed environments may limit the robot's movement and effectiveness.
- The water supply on the robot is finite, requiring refilling for prolonged operations. In situations where fire cannot be extinguished or maintained, having to refill the water tank will allow the fire to spread rapidly in the time it takes the vehicle to return to the operator, fill up, and return to the fire area.
- The system relies on human input through an app for navigation and fire suppression which makes it prone to human error or malfunctioning. Programming the vehicle to be fully autonomous operating will minimize human error and improve efficiency.

- The robot's operation time relies on battery capacity, if not recharging properly will make the unit inefficient for emergencies.

5.3. Alternatives

Several alternative approaches exist for fire extinguishing in hazardous environments. One alternative is drones with fire suppression that can access elevated areas and be deployed faster. However, their payload is limited, restricting the amount of fire-extinguishing material they can carry. There are also traditional firefighting methods like fire hoses and sprinkler systems, which are widely used, however, these methods rely on human interaction and are inefficient in hard-to-reach places. Another option is fully autonomous firefighting robots that utilize AI-based detection. Although this system requires little to no human interaction, they are significantly more expensive and complex to build and maintain. Ember Bot combines the advantages of remote operation with affordability, its ability to easily navigate through different terrains while being controlled in real-time makes it a practical alternative for first responders.

5.4. Impact

Ember Bot has environmental, societal, and ethical implications. Starting with environmental impact, the system minimizes water waste by targeting the base of the fire to extinguish it faster. By enabling rapid response to fires, it will also help reduce the environmental damage from uncontrolled fires. Now from a societal perspective, the vehicle enhances firefighter safety by reducing exposure to life-threatening conditions. It is essential to ensure the vehicle's functions are working efficiently in critical situations to prevent jeopardizing emergency response efforts, which poses an ethical concern. To emphasize, this system is not designed to replace firefighters but rather to assist them.