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

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Change Record

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

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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.

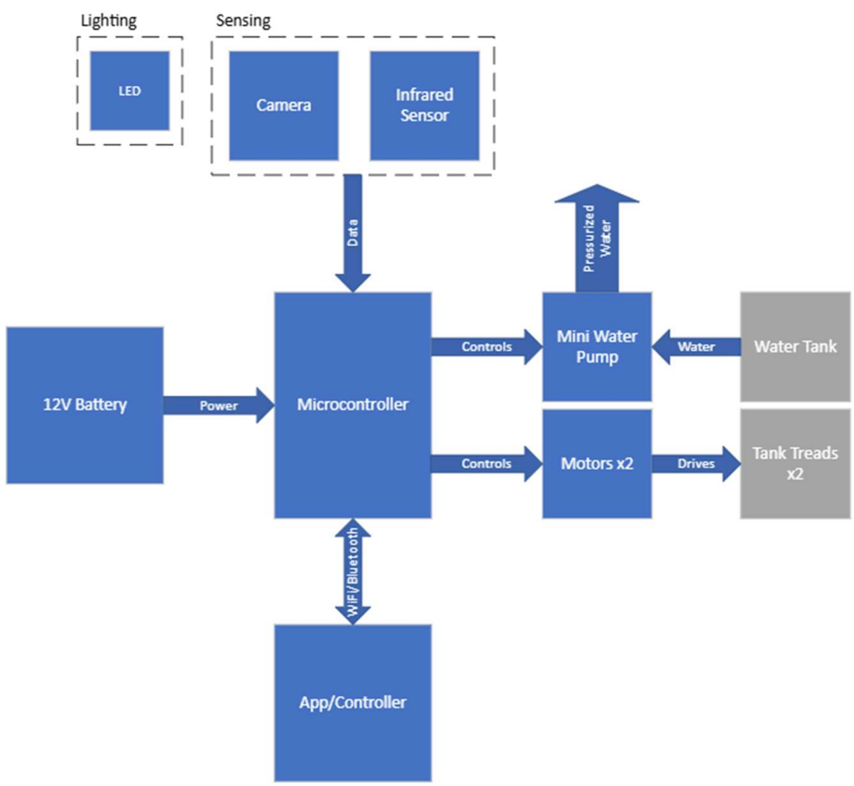

Figure 1. System Diagram of Ember Bot

2. Introduction

In fire emergencies, rapid response and safe intervention are critical. This document introduces Ember Bot, a firefighting robotic vehicle which 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.

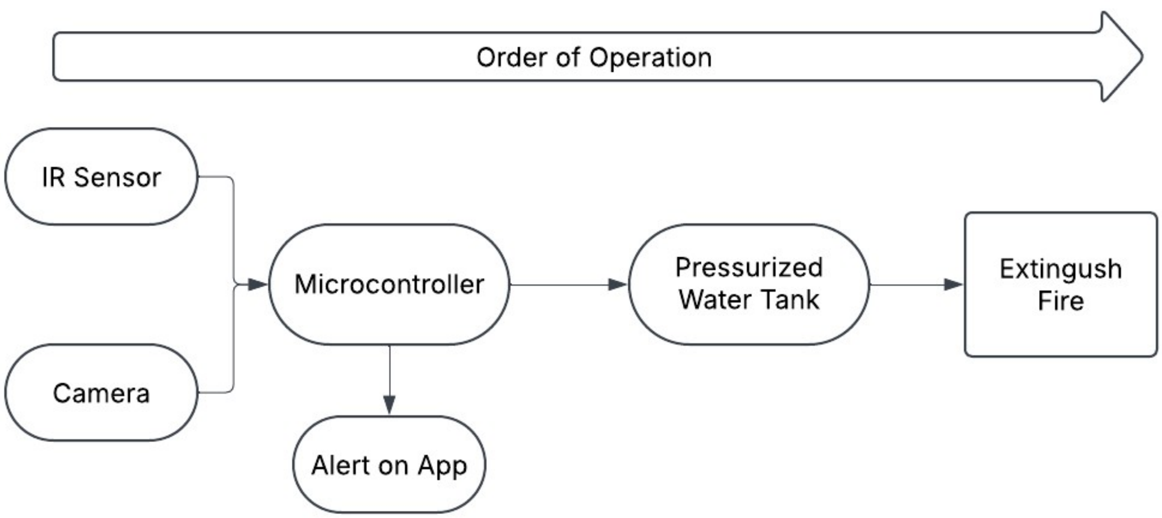

Figure 2. Order of Operation of Fire Suppression

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 which 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 fire in these high-risk areas. Scenarios of the possible usage of Ember Bot includes but 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: Fire Detection Subsystem, RC Car and Pump Subsystem, Power for the Robotic Vehicle, App and Controller for the Robotic Vehicle. These 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 controls 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.

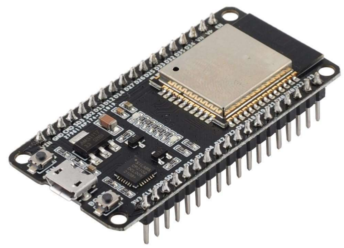

Figure 3. ESP-32 Microcontroller

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.

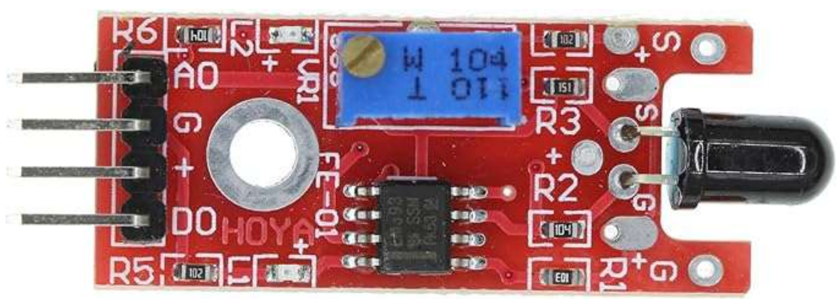

Figure 4. KY-026 IR Sensor

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 programed 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 for 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 provide guidance on 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 fire fighters in reaching hard to reach fires. Fire fighters 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 livestream on their phone 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 for 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 environment 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 e 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. led fires. Now from a societal perspective, the vehicle enhances firefighter safety by reducing exposure to life-threatening conditions. ns. 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.

EMBER BOT

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FUNCTIONAL SYSTEM REQUIREMENTS

REVISION – Draft
20 February 2025

FUNCTIONAL SYSTEM REQUIREMENTS
FOR
Ember Bot

PREPARED BY:

TEAM #30

APPROVED BY:

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Change Record

Rev.	Date	Originator	Approvals	Description
1	2/20/2025	Jonathan Chen		Draft Release

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1. Introduction

1.1. Purpose and Scope

This document defines the detailed technical requirements for Ember Bot. The purpose of this project is to create a specific targeted solution to the dangers of fires located in hard-to-reach areas or when first responders are unavailable. Designed to be used by fire-fighters primarily, Ember Bot provides any user with the ability to deal with small-scale fires that are unable to be dealt with by normal means. It aims to improve firefighter safety and efficiency by overcoming challenges posed by hazardous situations. Figure 1 demonstrates the functionality of Ember Bot, as integrated within the proposed CONOPS. The verification requirements for Ember Bot are continued in a separate Verification and Validation Plan.

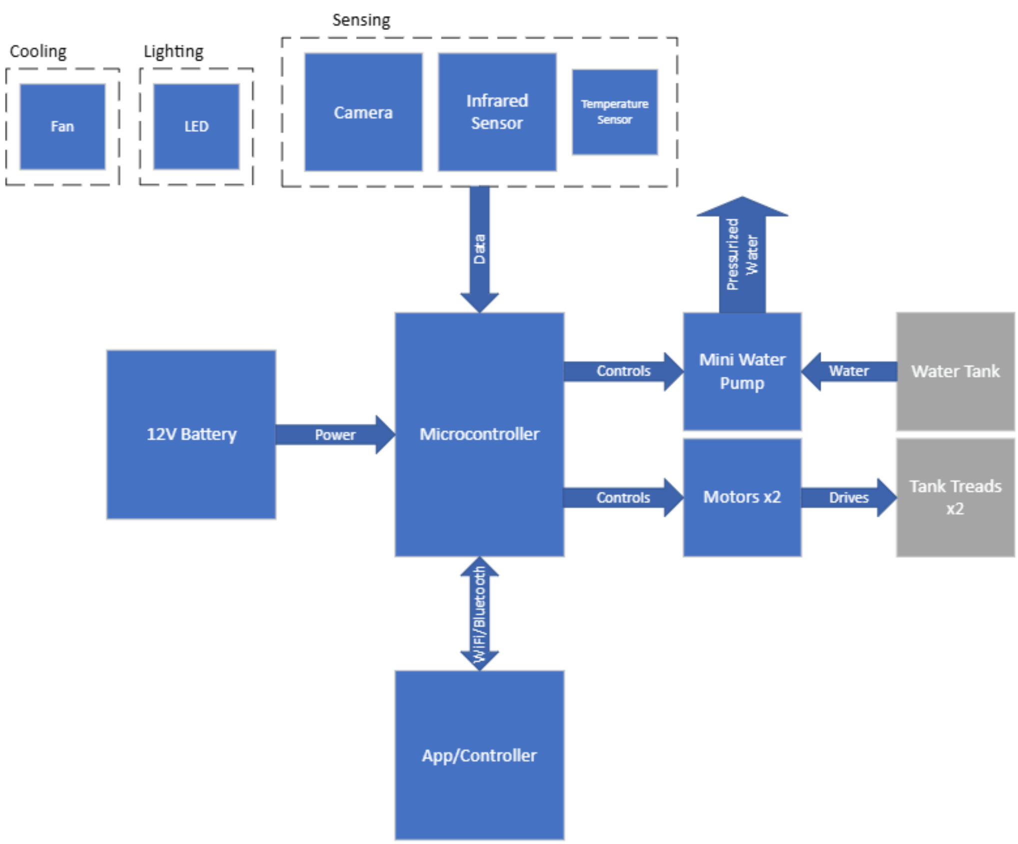

Figure 1. Functional System Diagram of Ember Bot

1.2. Responsibility and Change Authority

The team leader, Jonathan Chen, is responsible for ensuring that all specifications and requirements of Ember Bot are met. Any changes to the team's deliverables of the project must be approved by the team leader, Jonathan Chen, the sponsor, Zian Wang, and our designated TA, Swarnabha Roy. Subsystem owners are also accountable for ensuring their subsystem meets all requirements. The subsystem distribution is as follows:

- Jonathan Chen: Microcontroller and Fire Detection (IR & Camera)
- Yuwen Zheng: Application and Controller Design
- Nancy Ramirez Castillo: Power System
- Kevin Rivera: Car Design and Pump System

2. Applicable and Reference Documents

2.1. Applicable Documents

The following documents, of the exact issue and revision shown, form a part of this specification to the extent specified herein:

Table 1. Applicable Documents

Document Number	Revision/Release Date	Document Title
IEC 61508-1:2010	4/1/2010	Functional Safety of Electrical/Electronic Systems
C2-2017	2017	National Electrical Safety Code (R)
ISO 13849-1:2015	11/1/2015	Safety of Machinery – Safety-Related Parts of Control Systems
ISO 10218-1:2011	2011	Robots and Robotic Devices – Safety Requirements for Industrial Robots
IEC 61508-5:2010	2010	Functional safety of electrical/electronic/programmable electronic safety-related systems
NFPA 70:2023	2023	National Electrical Code (NEC)

2.2. Reference Documents

The following documents are reference documents utilized in the development of this specification. These documents do not form a part of this specification and are not controlled by their reference herein.

Table 2. Reference Documents

Document Number	Revision/Release Date	Document Title
IEEE Standard 802.15.4-2015	2015	Standard for Low-Rate Wireless Personal Wireless Network
IRJET-V612417	February 2019	Design & Implementation of RF-based Fire Fighting Robot

2.3. Order of Precedence

In the event of a conflict between the text of this specification and an applicable document cited herein, the text of this specification takes precedence without any exceptions.

All specifications, standards, exhibits, drawings, or other documents that are invoked as “applicable” in this specification are incorporated as cited. All documents that are referred to within an applicable report are for guidance and information only, except ICDs that have relevant documents considered to be incorporated as cited.

3. Requirements

Ember Bot, the fire-fighting robotic vehicle, is a proof of concept for additional assistance that could be deployed in the field by firefighter responders. In the following section, “fire detection” will refer to the system responsible for gathering the information to relay to the user. This includes infrared sensors and the camera. The term “vehicle operations” will refer to the system responsible for physical components within the vehicle such as movement, lighting, water nozzle control, and a fan and temperature sensor for cooling. The term, “app interface” will refer to the software program that users would use to control robotic vehicle operations.

3.1. System Definition

The Ember Bot is made of four subsystems, which are shown in Figure 2. The power subsystem has parts in both vehicle operations and fire detection. The detection and communication subsystem are exclusive to the fire detection portion. The lighting and cooling, water pump, and motor subsystems are also exclusive to the vehicle operations portion.

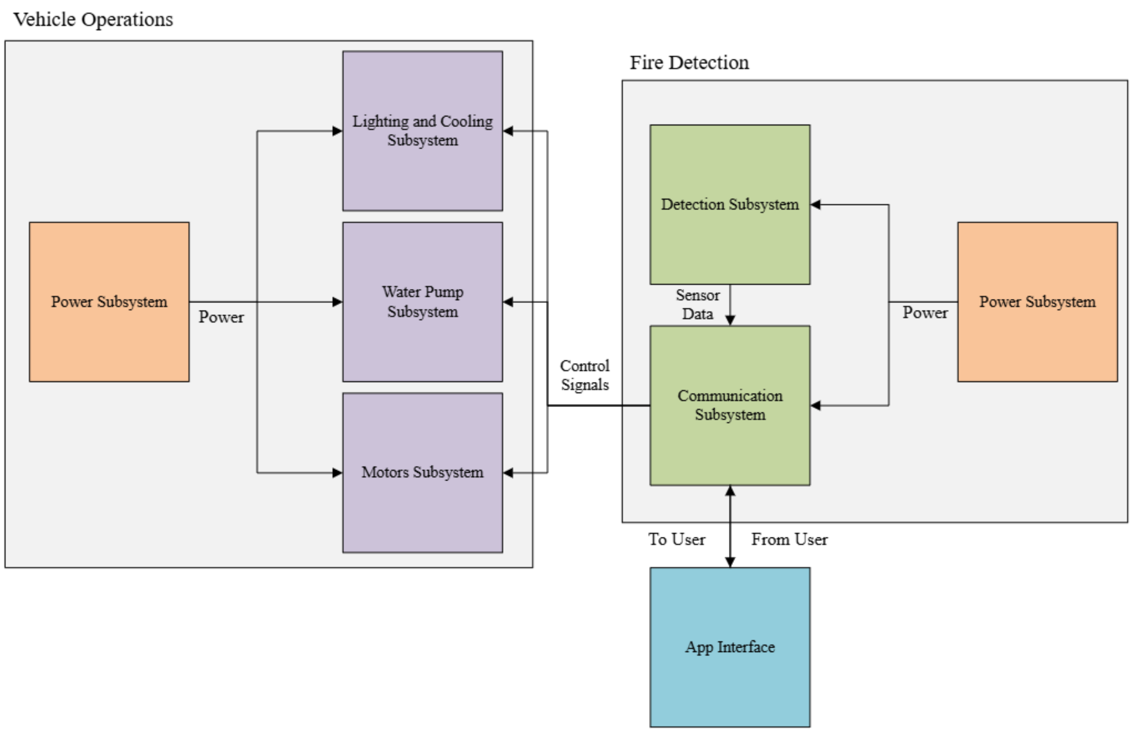

Figure 2. Block Diagram of System

The power subsystem consists of two 11.1V/2.2Ah lithium-ion batteries connected in series to provide enough power to the DC motors. A buck-converter steps down the voltage as needed for the sensors and ESP32. Additionally, the power subsystem will include a standard wall plug-in for the recharging of batteries, and PCB design to distribute power efficiently and integrate all components.

The motors subsystem contains two 24V DC motors and a dual-channel motor driver. There is one motor on each side of the robotic vehicle, driving a wheel connected to tank treads. The tank treads will give the robot the versatility of traversing potentially rough terrains. The DC motors will be driven by a dual-channel motor driver receiving signals from the communication subsystem.

The detection subsystem in Ember Bot gathers visual data and transmits it to the communication subsystem. It utilizes infrared sensors and a camera to detect environmental conditions and obstacles. The infrared sensors provide data on temperature variations and heat signatures, while the camera captures visual information for further processing. This data is then relayed to the communication subsystem, enabling real-time monitoring and decision-making.

The communication subsystem will collect sensor data and transmit it to the mobile app via Bluetooth. It will also receive commands from the app to control the water pump and motor subsystems, ensuring seamless operation by relaying instructions to the appropriate components and the desired subsystem.

For the water pump subsystem, there is a DC water pump and two servos to move the water nozzle. Both would receive signals from the communication subsystem. The water pump can be turned on and off to control the water output. The two servos can move the water nozzle to aim it wherever the user desires.

The lighting and cooling subsystem contains an LED strip, a temperature sensor, and a cooling fan. The LED strip would be lighting the way in front of the robot to assist in driving the robot. A temperature sensor would be placed inside the robot and once at a sufficiently high temperature is sent to the communication system and activates the cooling fan.

The mobile app subsystem displays real-time video recordings and data gathered from Ember Bot. Users can send the commands via a mobile app so that Ember Bot can locate and put out fires. The mobile app subsystem will contain user manuals, and help pages to provide additional assistance.

3.2. Characteristics

3.2.1. Functional / Performance Requirements

3.2.1.1. Communication Requirements

The Ember Bot should continuously send real-time video streams and data to the mobile app. It should also be able to continuously receive user commands sent from the mobile app. The Ember Bot should be able to operate and function within a maximum distance of 70 meters.

> *Rationale: The maximum communication distance is limited to the maximum operation distance of Bluetooth.*

3.2.1.2. Mobile App Warning Requirements

Under any circumstances, the mobile app should generate a warning within one minute to inform the user of any issues or emergency incidents Ember Bot may face. Warnings can provide users with information about how to troubleshoot different problems and take the next steps.

Rationale: One minute allows the Ember Bot systems to predict and analyze different incidents.

3.2.2. Physical Characteristics

3.2.2.1. Mass

The mass of the Ember Bot shall be less than or equal to 21 lbs.

Rationale: This would allow users to be able to easily carry and deploy it in the field.

3.2.2.2. Volume Envelope

The volume envelope of the Ember Bot shall be less than or equal to 5 inches in height, 14 inches in width, and 15 inches in length.

Rationale: A lower design would allow users to be able to drive the robot under debris or collapsed areas. The wide design will also allow the robot to carry more water inside.

3.2.2.3. Mounting

The mounting information for the Ember Bot subsystems shall be captured in the Ember Bot ICD.

Rationale: As the Ember Bot subsystems mount to the chassis, the interface between the two includes mechanical, electrical, and thermal details.

3.2.3. Electrical Characteristics

3.2.3.1. Inputs

a. The presence or absence of any combination of the input signals under ICD specifications applied in any sequence shall not damage the Ember Bot, reduce its life expectancy, or cause any malfunction, either when the unit is powered or when it is not.

b. No sequence of command shall damage the Ember Bot, reduce its life expectancy, or cause any malfunction.

Rationale: By design, should limit the chance of damage or malfunction by user/technician error.

3.2.3.2. Power Consumption

a. The maximum peak power of the system shall not exceed 48.84 watts.

Rationale: This is a requirement to ensure continuous operation for motors, but this power should not directly go to smaller components in the power circuit.

3.2.3.3. Input Voltage Level

The input voltage level for the Ember Bot shall be 22.2V.

Rationale: The highest voltage of 25.2V is only for the two DC motors; all other components will have a step-down voltage of 12V, 3.3V, or less.

3.2.3.4. Connectors

The Ember Bot will have a wall plug input connector that will recharge the batteries when not in use.

3.2.3.5. External Commands

The Ember Bot shall document all external commands in the appropriate ICD.

Rationale: The ICD will capture all interface details from the low-level electrical to the high-level packet format.

3.2.4. Outputs

3.2.4.1. Data Output

The Ember Bot will be able to show the user the distance of the Ember Bot from the starting point so that the Ember Bot does not travel outside the maximum distance for Bluetooth access.

Rationale: The distance information shows directly on the Mobile App Control page to make sure users do not lose control of Ember Bot.

3.2.4.2. Diagnostic Output

The users will be able to see warnings on the Mobile App when there are any problems with the Ember Bot. The warnings will show information to help identify and troubleshoot different problems.

Rationale: The user can get immediate help and guidance on both operation and troubleshooting Ember Bot.

3.2.4.3. Raw Video Output

The Mobile App will show real-time recordings from the Ember Bot for detecting fire and controlling the Ember Bot to put out the fire.

Rationale: Users can directly locate the fire and take action.

3.2.5. Environmental Requirements

3.2.5.1. Pressure (Altitude)

The Ember Bot is designed to operate under air pressure at an altitude from sea level (0 ft) to 8751 ft. All the sensors used in the design of Ember Bot will not be affected by altitude.

Rationale: The highest natural point in Texas is 8751 ft (The Guadalupe Peak).

3.2.5.2. Thermal

Ember Bot, as proof of concept, shall be designed to withstand and operate in temperatures of -20°F to 125°F.

> *Rationale: As the robot is designed to be deployed in environments experiencing fires, it must be able to operate in high-temperature conditions. A cooling fan will be used to keep the temperature in this range.*

3.2.5.3. External Contamination

The Ember Bot is designed to operate in all conditions of weather and contamination. Dust, pollen, and insects will not interfere with the operation of Ember Bot. However, weather and contamination such as haze and fog may affect the visibility of Ember Bot. Icy roads may cause Ember Bot to slip.

> *Rationale: As the Ember Bot is designed to put out fires, it will be able to operate in extreme weather and conditions. However, it is outside the scope of this project for Ember Bot to fight against extreme natural forces such as tornados and hail.*

3.2.5.4. Rain

The Ember Bot is designed to put up a fire using a pressurized water pump. All the subsystems of Ember Bot are required to be protected from water and rain. However, flooding may prevent Ember Bot from moving and thus can destroy the interconnection of each subsystem.

> *Rationale: It is unlikely that Ember Bot is operated in rain or flood due to fire hazards that may not exist under these conditions.*

3.2.5.5. Humidity

The Ember Bot is designed to operate in a relative humidity range from 5% to 70%.

> *Rationale: This range includes considerations like temperature and humidity levels in cities like Texas. This range also considers sea water since salt will accelerate the rust of steel. Designing a system outside this humidity range is outside the scope of this project.*

3.2.6 Failure Propagation

The Ember Bot is designed to complete tasks within the control of the users. Each subsystem is designed to prevent failure propagation.

3.2.6.1 Power Supply Failure

Battery depletion, voltage drops, or buck converter failure will lead to the ESP32 shutting down, the water pump burning out, motors stalling, and sensors failing making Ember Bot inoperable in critical scenarios.

3.2.6.2 Connectivity Failure

Ember Bot will be controlled on a phone via Bluetooth that can range to a maximum of 70 meters. If the app malfunctions or loses connections, the bot will not receive commands leading to an inability to navigate or activate the water pump if near fire.

3.2.6.3 No Fire Response

Fire detection comes from the user viewing the IR sensor and camera on the app, if no fire is detected it will lead to delayed or no response which can leave the robotic vehicle in a vulnerable position to overheating or damage from an undetected fire.

3.2.6.4. Ineffective Fire Suppression

The motor failure or pump malfunctions will disable Ember Bot from reaching the fire or extinguishing it, reducing its fire-fighting capability.

4. Support Requirements

4.1.1 Mobile Device with Bluetooth Access

To control the Ember Bot and use the system as designed, the user must have a mobile device with access to Bluetooth. The mobile device can be either an Android or IOS system. The user will be able to view the application and control page in the app.

Rationale: Other forms of accessing the mobile app are outside the scope of this Project.

4.2.2 User Distance

The user must stay within a distance range that is less than 70 meters away from the Ember Bot so that the Ember Bot can be connected to the Mobile Device through Bluetooth.

Rationale: This will be the largest distance that the Ember Bot can operate.

4.2.3. Maintenance

The user must maintain and test the Ember Bot at least once every two months to ensure no parts are damaged and the system is working.

Rationale: The system is designed so that users will be able to address any issues using the help page and user manual.

Appendix A: Acronyms and Abbreviations

A	Amperes
BIT	Built-In Test
FOV	Field of View
ICD	Interface Control Document
LED	Light-Emitting Diode
MHz	Mega Hertz (1,000,000 Hz)
PCB	Printed Circuit Board
RF	Radio Frequency
W	Watt
USB	Universal Serial Bus
lb	Pound
Ah	Amp-hour

Appendix B: Definition of Terms

Fire Detection	Sensors and cameras relay data to the communication subsystem. Information is then sent to the app interface for the user.
Vehicle Operations	Components serve different components for running robotic vehicles. Receiving controls from the communication subsystem.

EMBER BOT

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INTERFACE CONTROL DOCUMENT

REVISION – Draft
20 February 2025

INTERFACE CONTROL DOCUMENT
FOR
Ember Bot

PREPARED BY:

TEAM #30

APPROVED BY:

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1. Overview

The Interface Control Document (ICD) for Ember Bot will provide detailed explanations of how the multiple components/subsystems in the Concept of Operations and the Functional System Requirements will be executed. The ICD will include the physical descriptions of the various components and the technical requirements of Ember Bot. Additionally, this document will outline how each subsystem will integrate to meet the goals and requirements specified in the Concept of Operations and the Functional System Requirements documents.

2. References and Definitions

2.1. References

IRJET-V612417
Design & Implementation of RF-based Fire Fighting Robot
February 2019

IEEE Standard 802.15.4-2015
Standard for Low-Rate Wireless Personal Wireless Network
2015 Revision

2.2. Definitions

A	Amperes
BIT	Built-In Test
ICD	Interface Control Document
LED	Light-Emitting Diode
MHz	Megahertz (1,000,000 Hz)
PCB	Printed Circuit Board
RF	Radio Frequency
W	Watt
Ah	Amp-hour
lb	Pound
mA	Milliamp

3. Physical Interface

3.1. Weight

The Ember Bot will weigh less than 21lbs. This allows for an average person to be able to lift it and deploy it. The water tank will also be empty when first deployed, with it being filled only when the robot is used.

Table 1. Ember Bot Weight Specifications

Component	Weight
Vehicle shell	Est. 11.24 lbs
Water Pump	1.6 lbs
DC Motors	0.97 lbs
Cooling Fan	0.11 lbs
Temperature Sensor	0.0198 lbs
Water Tank with Water	Est. 4.17 lbs
Infrared Sensor	0.0198 lbs
Camera Module	0.044 lbs
Servo Motors	0.599 lbs
Batteries	0.78 lbs
Motor Driver	0.136 lbs
Microcontroller	0.044 lbs
Buck Converter	0.071 lbs
Total	19.82 lbs

3.2. Dimensions

3.2.1 Dimension of Vehicle Operations

Table 2. Vehicle Operations Dimension Specifications

Component	Length	Width	Height
LED Strip	Est. 6”	Est. 0.5”	N/A
Cooling Fan	2.35”	0.98”	2.38”
Water Pump	6.5”	4”	2.2”
Servo Motor	1.57”	0.79”	1.41"
Temperature Sensor	1.26”	0.55”	N/A
DC Motors	5.5”	1.5”	1.25”
Motor Driver	2.5”	2.95”	0.6”
Buck Converter	0.55”	0.83”	0.55”
Solar Panel	16”	13.1”	0.8”

3.2.2 Dimension of Fire Detection

Table 3. Fire Detection Dimension Specifications

Component	Length	Width	Height
Camera Module	1.06”	1.57”	N/A
Infrared Sensor	1.42”	0.63”	N/A
Microcontroller	1”	1.9”	N/A

3.2.3 Dimension of Vehicle Frame

The dimensions of the robot are an estimated length of 15”, a width of 13.5”, and a height of 5”. The dimensions could be changed to accommodate the components inside the robot and water holder.

3.3 Mounting Locations

3.3.1. Usage of Ember Bot

The robotic vehicle can be placed in a flat unobstructed area. Once placed on the ground, the water tank inside of the robot can be filled to a maximum of half a gallon of water. Once filled to the desired amount, it can be turned on and operated via the user.

3.3.2. Mounting of Sensors

The sensors on Ember Bot will be positioned to ensure optimal data collection. Infrared sensors will be placed at appropriate heights and angles to maximize detection accuracy, while the camera module will be mounted to provide a clear, unobstructed field of view. Mounting options will be selected based on stability and environmental conditions to ensure reliable sensor performance.

3.3.3. Mounting of Battery & Power Converter

The batteries will be mounted on each side wall of the chassis to optimize space for all components. The PCB and power converter will be placed in the middle of the chassis having equal distance between sensors and other equipment.

3.3.4. Mounting of Microcontroller

The microcontroller will be housed in a waterproof, dust-resistant enclosure within the chassis, ensuring protection from environmental factors such as moisture, dirt, and debris. All cabling will be routed through sealed cable glands or waterproof connectors to maintain enclosure integrity while allowing efficient data transmission and power distribution. This setup will enhance the durability, reliability, and longevity of the electronics subsystem in various operating conditions.

4. Thermal Interface

4.1. Cooling of Battery

The battery will be air-cooled using a fan that activates when the internal temperature exceeds a set threshold, as detected by a temperature sensor. The heat generated by the battery will be dissipated through a vent.

5. Electrical Interface

5.1. Primary Input Power

Power for Ember Bot will be supplied via an 11.1-volt battery alongside additional support 2V batteries, which will be used to supply power to all appropriate subsystems when needed. The voltage will be regulated, with buck converters used to step down 12V to appropriate levels for components that require lower operating voltages.

5.2. Signal Interfaces

The KY-026 flame sensors will communicate with the computing subsystem by outputting an analog voltage signal once within the specified wavelength (760nm – 1100nm), which will interpret flame intensity and temperature readings.

5.3. Voltage and Current Levels

The full voltage available will be used to power both 24V motors before being stepped down to 12V to power the water pump and then to the lowest voltage of 3.3V which will be used for sensors, microcontroller, LED light, ESP32, and camera module. The current will be no more than 2.2A which will be used mostly by the motors and then decreased to milliamps for all other components, reaching the lowest to 1mA.

5.4. User Control Interface

The only user interface for Ember Bot's application will be an application-based GUI, allowing users to monitor the sensor data collected and control Ember Bot in real-time. Additional usage of the pump and other additional settings are configured into the application. No additional user interface is required for this system.

6. Communications / Device Interface Protocols

6.1. Wireless Communications (Wi-Fi) & Bluetooth

All communication between Ember Bot and communication with the controller will be managed through Wi-Fi and/or Bluetooth, with the option to integrate RF communication if needed. This implementation adheres to the IEEE 802.15.4-2015 standard for wireless connectivity.

6.2. Microcontroller Input & Output

Ember Bot's ESP32 microcontroller features a range of digital and analog I/O pins, capable of reading and transmitting signals within a 0V-3.3V range. This voltage level is compatible with all the sensor communication protocols used in the system, ensuring reliable data and control.

6.3. Video Interface

The video interface is managed by an ESP32-CAM connected to the ESP32 microcontroller via GPIO pins. The camera streams video to the web application over Wi-Fi/Bluetooth, enabling remote access and control. This meets the requirements of all the protocols mentioned above.

EMBER BOT

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

MILESTONE & VALIDATION PLAN

REVISION – Draft
20 February 2025

MILESTONE & VALIDATION PLAN
FOR
Ember Bot

PREPARED BY:

TEAM #30

APPROVED BY:

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Jonathan Chen 2/20/25

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John Lusher, P.E. 2/20/25

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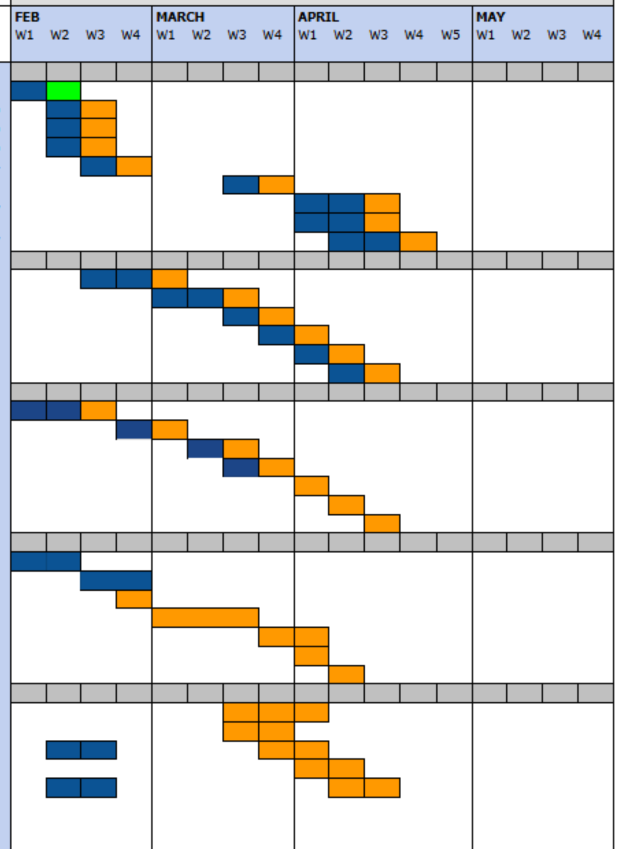
Swarnabha Roy 2/20/25

Ember Bot Project Schedule

Deliverable/Task	Owner	Duration	Note
Overall Deliverables			
ConOps	All	2w	Due 2/5
FSR + ICD	All	2w	Due 2/20
Validation Plan	All	2w	Due 2/20
Milestone Plane	All	2w	Due 2/20
Midterm Presentation	All	2w	Due 2/24
Status Update Presentation	All	2w	Due 4/2
Final Presentation	All	3w	Due 4/16
Final Demo	All	3w	Due 4/21
Final Report	All	3w	Due 4/27
Microcontroller & Fire Detection			
ESP32 Installation + Start-Up	Jonathan	3w	
ESP32 Framework	Jonathan	3w	
Camera Module	Jonathan	2w	
IR Sensor Detector	Jonathan	2w	
Light Source	Jonathan	2w	
Microcontroller Connection w/ Subsystems	Jonathan	2w	
App Development			
Create wireframe and overall structure	Yuwen	3w	
Create clickable prototype	Yuwen	2w	
Create User Interface Design	Yuwen	2w	
Test the app	Yuwen	2w	
Create User Mannual within app	Yuwen	1w	
Create User Help page within app	Yuwen	1w	
Finalize App Design	Yuwen	1w	
Power System			
Design circuit schematic	Nancy	2w	
Breadboard Assemble and Testing	Nancy	2w	
Power Efficiency and Load Testing	Nancy	1w	
PCB Design	Nancy	2w	
PCB Testing	Nancy	3w	
Thermal and Safety Analysis	Nancy	1w	
Validate Recharging	Nancy	1w	
Pump System + Car			
Verify Vehicle Movement	Kevin	2w	
Set up Lighting and Cooling	Kevin	2w	
Movable Nozzle	Kevin	2w	
Water Pump System	Kevin	3w	
Creating Vehicle Frame	Kevin	2w	



Annotations:

Critical	1	Completed	
External dependency	2	Expected Completion	
Postponed	3	In Progress	
		Behind Schedule	

Validation Plan for Ember Bot

Status Indicators	
Completed	
In Progress	
Behind Schedule	

Task	Deadline	Current Status	Color Code
Understand & Research	1/30/2025	Completed	
ConOPS Completed	2/5/2025	Completed	
Components Ordered	2/18/2025	Completed	
FSR, ICD, Milestones, and Validation Plan Completed	2/20/2025	Completed	
Midterm Presentation	2/24/2025	In Progress	
Parts Received	TBD	In Progress	
Breadboard Testing	2/28/2025	In Progress	
Vehicle Movement	3/18/2025	In Progress	
PCB Designed + Ordered	3/19/2025	In Progress	
ESP32 Framework Completed	3/25/2025	In Progress	
Pump System Completion	3/25/2025	In Progress	
Primary App Design Completed	4/1/2025	In Progress	
PCB Testing Complete	4/2/2025	In Progress	
Microcontroller System Set-up	4/8/2025	In Progress	
Power System Tested w/ Car	4/8/2025	In Progress	
Final Presentation	4/16/2025	In Progress	
Final Demo	4/21/2025	In Progress	
Final Report	4/27/2025	In Progress	