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REPORT

A Prototype Autonomous Fire Detecting And Firefighting Robot

Full Name: DAO VINH KHANG

Bachelor of Science with Honours in Computing

ID: GCS200222

(Email: dk9621h@gre.ac.uk)

Article

A Prototype Autonomous Fire Detecting And Firefighting Robot

Abstract:

Background: In urban environments, particularly in high-rise buildings, ensuring safety against fire incidents is paramount. Traditional fire safety measures, while effective to a certain extent, may encounter limitations in adequately addressing the unique challenges posed by high-rise structures. Therefore, there is a critical need for innovative solutions tailored specifically to enhance fire safety in high-rise buildings.

This Prototype proposes the development of a comprehensive High-Rise Building Fire Safety System (HRBFSS) designed to mitigate the risks associated with fire incidents in tall structures. Leveraging cutting-edge technologies such as IoT (Internet of Things), advanced sensors, and data analytics, the HRBFSS aims to provide a proactive and intelligent approach to fire prevention, detection, and evacuation.

The system will consist of multiple components strategically integrated throughout the high-rise building, including smoke and heat detectors, emergency lighting, fire suppression systems, and intelligent evacuation guidance systems. These components will be interconnected through a robust IoT infrastructure, allowing real-time monitoring and control of fire safety measures.

Furthermore, the HRBFSS will incorporate predictive analytics algorithms capable of analyzing environmental data, occupant behavior patterns, and historical fire incident data to anticipate and mitigate potential fire risks. Through proactive risk assessment and early detection capabilities, the system aims to minimize the likelihood of fire outbreaks and facilitate swift and effective response in the event of an emergency.

The expected outcomes of this Prototype include a significant enhancement in fire safety standards for high-rise buildings, reduced response times in case of fire incidents, and improved occupant evacuation procedures. By leveraging technology to address the unique challenges of vertical structures, the HRBFSS aims to create safer and more resilient urban environments for residents and occupants.

In conclusion, the High-Rise Building Fire Safety System represents a pioneering initiative in the field of fire safety engineering, offering tailored solutions to address the specific needs of high-rise structures. Through innovation, collaboration, and a proactive approach to fire safety, this Prototype aims to set new standards for building resilience and occupant safety in urban environments.

Keywords: Advanced technology, Urban safety, High-rise buildings, Fire safety, IoT, Internet of Things, Sensor networks, Predictive analytics, Emergency evacuation, Risk assessment, Building resilience

Expression of Gratitude for Guidance and Support in Completing the Prototype

Dear Mr. Sam and Mr. Bao

I hope this message finds you both well. I am writing to express my heartfelt gratitude for your invaluable guidance and support throughout the development of my Prototype . Your expertise and encouragement have been instrumental in shaping the Prototype into a more comprehensive and successful endeavor.

Mr. Sam, I am truly grateful for your insightful guidance and suggestions on integrating various IoT methods to enhance the functionality and efficiency of the Prototype . Your expertise in this field has broadened my perspective and enabled me to explore innovative solutions to complex challenges. Your mentorship has not only enriched my knowledge but also inspired me to push the boundaries of what I thought was possible.

Mr. Bao, I want to extend my sincere appreciation for your contribution to the Prototype by creating thought-provoking challenges that have significantly improved its overall quality. Your ability to identify key areas for improvement and your willingness to explain the underlying concepts have been invaluable in helping me understand and address critical issues. Your dedication to excellence has motivated me to strive for the highest standards in every aspect of the Prototype .

Together, your guidance and support have transformed the Prototype , making it more robust, efficient, and impactful. Your insights and contributions have not only helped me overcome challenges but have also inspired me to think creatively and approach problems with confidence. I am deeply grateful for your mentorship and support, and I look forward to applying the knowledge and skills gained from this experience in future endeavors.

Once again, thank you, Mr. Sam and Mr. Bao, for your invaluable contributions to the success of the Prototype . Your guidance and support have made a lasting impact, and I am truly grateful for the opportunity to learn from you.

Warm regards,

[Dao Vinh Khang]

[GCS200222]

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Chapter 1: Introduction to House Prices Prediction using Multiple Regression in Machine Learning

1.1 Overview

In the contemporary landscape of fire management and emergency response, the introduction of automated robot solutions represents a transformative leap forward. With the aim of enhancing firefighting capabilities and mitigating the risks associated with fire incidents, these innovative solutions integrate cutting-edge technologies such as IoT and machine learning.

Amidst the evolving urban safety dynamics and the increasing frequency of fire emergencies, traditional firefighting methodologies encounter growing challenges. Researchers and industry experts are turning to machine learning techniques as demonstrated by FireTech Innovations (2023), recognizing their potential to analyze vast datasets and derive actionable insights for optimized fire management strategies.

As highlighted by SafetyTech Dynamics (2022), the utilization of regression models within automated robot solutions facilitates predictive analytics, enabling real-time decision-making and adaptive fire suppression mechanisms. Furthermore, the integration of Random Forest Machine Learning algorithms showcases the versatility of predictive modeling techniques for fire incident prediction and management.

In the domain of automated fire management solutions, sensor data plays a pivotal role in enhancing operational efficiency and situational awareness. Leveraging insights from ultrasonic sensors, RFID systems, and line detection sensors, these automated robots can navigate hazardous environments, identify fire sources, and execute precise firefighting maneuvers autonomously.

By synergistically integrating IoT infrastructure and machine learning algorithms, automated robot solutions aim to redefine fire management paradigms, offering rapid response capabilities, proactive incident prediction, and ultimately, safeguarding lives and property from the devastating impacts of fires.

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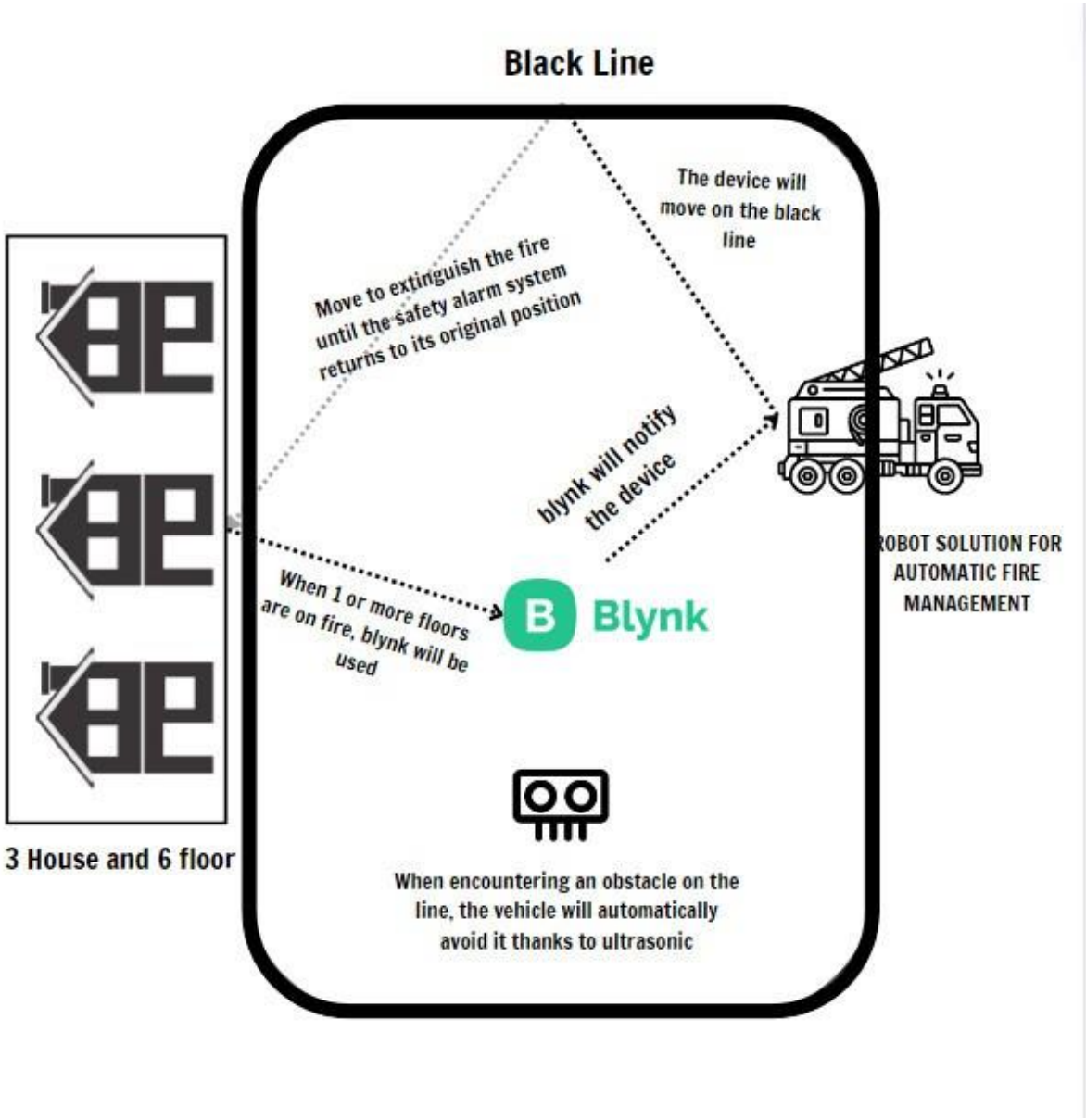


Figure 1 Autonomous Fire-Fighting Vehicle Navigation Flowchart

1.2 Motivations

The motivation behind the "A PROTOTYPE AUTONOMOUS FIRE DETECTING AND FIREFIGHTING ROBOT" Prototype stems from the pressing need to revolutionize traditional firefighting methods and address the evolving challenges faced by modern urban environments. Several key factors drive the development of this innovative solution:

Enhanced Fire Response Capabilities: Traditional firefighting methods often face limitations in terms of response time and accessibility, particularly in densely populated urban areas. The Prototype aims to overcome these limitations by introducing autonomous firefighting robots equipped with motion sensors. These robots can swiftly detect and respond to fire incidents, augmenting the capabilities of human firefighters and enhancing overall response efficiency.

Mitigation of Human Risk: Firefighting is inherently dangerous, exposing firefighters to various hazards and risks. By deploying autonomous firefighting robots, the Prototype seeks to mitigate these risks by minimizing the need for human intervention in hazardous environments. Motion sensor technology enables the robots to navigate through fire-affected areas autonomously, reducing the exposure of human firefighters to potentially life-threatening situations.

Optimization of Firefighting Operations: Urban firefighting operations often face challenges related to congestion, limited access, and resource allocation. The Prototype endeavors to optimize firefighting operations by introducing robots capable of autonomously navigating through complex urban environments. By leveraging motion sensors, these robots can identify the most efficient routes, circumvent obstacles, and allocate resources dynamically, thereby enhancing operational efficiency and effectiveness.

Adaptation to Urban Dynamics: Urban environments are characterized by rapid population growth, increasing infrastructure complexity, and evolving urban dynamics. Traditional firefighting methods may struggle to keep pace with these changes. The Prototype recognizes the need for adaptive firefighting solutions that can navigate through congested urban landscapes and respond to dynamic fire scenarios effectively. Autonomous firefighting robots equipped with motion sensors offer a versatile and scalable solution to address the challenges posed by urban dynamics.

Advancements in Sensor Technology: Recent advancements in sensor technology, particularly in the field of motion sensors, have opened up new possibilities for firefighting applications. By integrating state-of-the-art motion sensors into autonomous firefighting robots, the Prototype leverages these technological advancements to enhance situational awareness, navigation capabilities, and overall firefighting effectiveness.

In summary, the motivations driving the "A PROTOTYPE AUTONOMOUS FIRE DETECTING AND FIREFIGHTING ROBOT" Prototype revolve around the imperative to improve fire response capabilities, mitigate human risk, optimize firefighting operations, adapt to urban dynamics, and leverage advancements in sensor technology to address the evolving challenges of modern firefighting in urban environments.

1.3 Objectives

In this Prototype , there are several important goals that I focused on:

Automatic fire suppression management:

We develop an automatic firefighting robot system with the ability to automatically detect and extinguish fires, reduce response time and improve the ability to respond to fire incidents.

Optimize response time:

Deploying automatic robots helps minimize the response time of firefighting forces, ensuring quick and effective response to fire and explosion incidents.

Increased safety for firefighters:

The system allows firefighters to operate in hazardous environments without direct exposure to the risk of fire and explosion, increasing safety and protecting the health of employees.

Optimized route navigation:

Build an intelligent system that automatically navigates robots, avoids obstacles and chooses the optimal route, minimizing travel time and optimizing operating efficiency.

Forecasting and preventing risks:

Using data from sensors to predict and prevent fire risks helps minimize loss of life and property through timely preventive measures.

The steps to get the raw data of the information will be shown below:

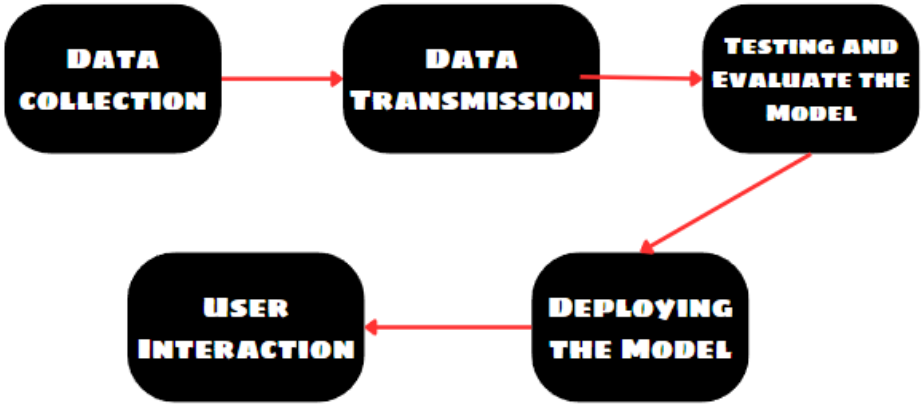


Figure 2 Data Integration Flow for A PROTOTYPE AUTONOMOUS FIRE DETECTING AND FIREFIGHTING ROBOT

In the opening chapter, I delineated the scope of my Prototype and outlined its objectives. Moving forward, the subsequent chapters will delve into various facets of this endeavor, encompassing an introduction to the dataset, an exposition of my methodology and findings, and a demonstration of the application.

Chapter 2: System Overview and Data Acquisition

2.1 System Architecture.

The system architecture of the Robotic Solution for Automated Fire Management includes a complete set of components and functions for effective fire detection, suppression and management. The architecture is meticulously designed to integrate various sensors, actuators,

microcontrollers and communication modules to create a powerful and responsive firefighting robot. The main components of the system architecture are outlined below:

Firefighting robot: The foundation of the system, the firefighting robot, is equipped with a series of sensors and actuators to perform automatic firefighting operations. The robot confidently uses sensor data to navigate the environment, detect fires, avoid obstacles and extinguish the flames with a water pumping mechanism.

Sensor:

Road sensors: These sensors are used for precise road tracking, allowing the robot to navigate along black lines with maximum precision to reach predetermined destinations efficiently.

Ultrasonic sensors: Ultrasonic sensors are strategically placed to detect obstacles, helping the robot detect and navigate around physical obstacles in its path with unwavering confidence .

Infrared sensors: Infrared sensors act as vigilant fire detectors, allowing the robot to promptly detect heat signatures associated with fires and trigger immediate response actions.

RFID sensors: RFID sensors play a key role in precise location determination, allowing the robot to distinguish specific zones or zones within its operating environment, such as a home or rescue station. fire.

Actuator:

Water pump: The water pump mechanism takes on the important responsibility of quickly spraying water to extinguish a fire. It is activated automatically upon fire detection or manually via remote control commands, ensuring quick and decisive action.

Microcontrollers:

ESP32 Controller: The firefighting robot is cleverly equipped with two ESP32 microcontrollers, which interact seamlessly with each other for meticulous coordination in sensor data processing, decision making and transmitter control. dynamic. One ESP32 serves as the main controller on the robot, while the other ESP32 facilitates seamless communication with external devices and networks, such as the Blynk IoT platform.

Blynk IoT Platform: The Blynk IoT Platform serves as the central interface for remote monitoring, control, and data visualization. It allows users to carefully monitor the status of the firefighting robot, receive real-time warnings and notifications, and precisely control its operations remotely. The ESP32 controller communicates seamlessly with the Blynk platform using secure authentication tokens, ensuring uninterrupted integration and interaction.

Custom Android App: A meticulously crafted custom Android app complements the Blynk IoT platform by providing a seamlessly integrated alternative user interface for vigilant monitoring and precise control of the robot fire fighting. The app interfaces fluently with the Blynk platform, allowing users to easily access the same comprehensive functions and features from their mobile devices.

Wireless communication: ESP32 controllers communicate seamlessly wirelessly with each other and external devices using a powerful Wi-Fi connection. This enables uninterrupted real-time

data exchange, precise command execution, and alert status updates between the firefighting robot, the Blynk IoT platform, and the custom Android app.

Image Observe the image below about the system overview of the Automatic Fire Fighting Management Robot Solution:

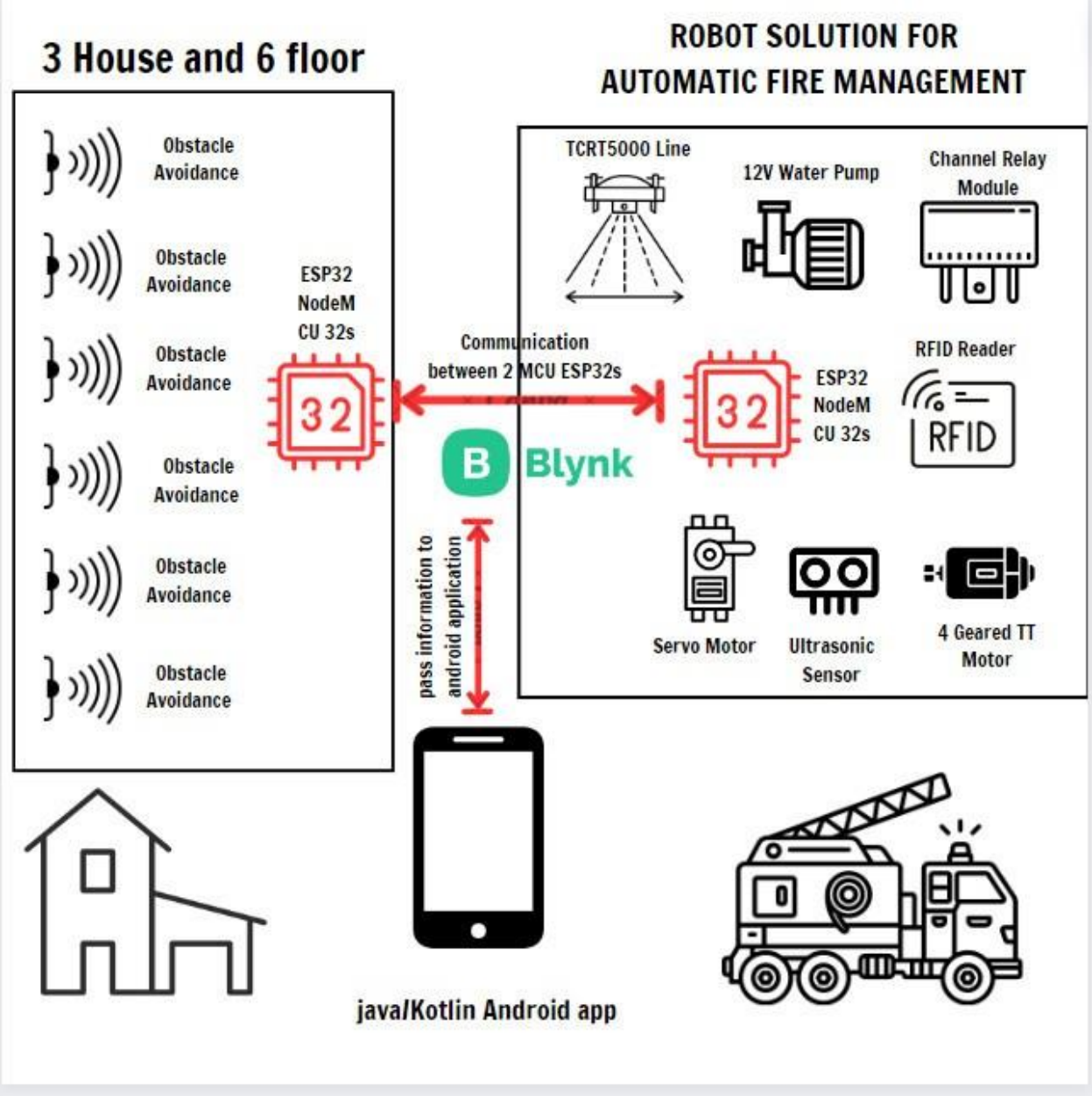


Figure 3: System Architecture of the Automated Firefighting Robot with Blynk Integration.

2.2 Components and Hardware Description

The A Prototype Autonomous Fire Detecting And Firefighting Robot integrates a diverse range of components and hardware meticulously selected to ensure optimal performance, reliability, and efficiency in firefighting operations. Each component serves a specific purpose within the system, collectively contributing to the seamless execution of firefighting tasks. The following sections provide a comprehensive description of the key components and hardware utilized in the system:

2.2.1 Firefighting Robot

The firefighting robot serves as the primary operational unit within the system, embodying the core functionalities of fire detection, navigation, obstacle avoidance, and fire suppression. Key features of the firefighting robot include:

Chassis: The chassis forms the structural framework of the robot, providing support and housing for all internal components. It is designed to withstand rugged environments and navigate challenging terrains effectively.

Sensors: A suite of sensors, including line sensors, ultrasonic sensors, infrared sensors, and RFID sensors, equips the robot with comprehensive environmental perception capabilities. These sensors enable the robot to navigate along predefined paths, detect obstacles, identify fire incidents, and determine precise locations within its operational environment.

Actuators: Actuators, such as motors and servos, facilitate the physical movement and manipulation of the robot. Motorized wheels enable locomotion, while servo motors control the orientation of sensor modules and the water pump mechanism.

Water Pump Mechanism: The water pump mechanism comprises a high-pressure water pump, water reservoir, and spray nozzles. Upon fire detection, the water pump is activated to propel pressurized water through the spray nozzles, effectively suppressing flames and extinguishing fires.

2.2.2 Microcontrollers

The system incorporates two ESP32 microcontrollers, each fulfilling distinct roles in orchestrating and coordinating the operation of the firefighting robot:

Primary Controller: One ESP32 microcontroller serves as the primary controller onboard the firefighting robot. It is responsible for sensor data acquisition, processing, decision-making, and actuator control. The primary controller executes autonomous navigation algorithms, fire detection routines, obstacle avoidance strategies, and water pump activation sequences.

Secondary Controller: The secondary ESP32 microcontroller facilitates seamless communication between the firefighting robot and external devices, networks, and user interfaces. It establishes and maintains Wi-Fi connectivity, interfaces with the Blynk IoT platform, and manages data exchange with the custom Android application.

2.2.3 Communication Modules

Wireless communication modules enable real-time data exchange, remote monitoring, and control of the firefighting robot from external devices and networks:

Wi-Fi Module: The ESP32 microcontrollers are equipped with integrated Wi-Fi modules, enabling wireless communication and networking capabilities. Wi-Fi connectivity facilitates seamless interaction between the firefighting robot, the Blynk IoT platform, and the custom Android application.

Blynk IoT Platform: The Blynk IoT platform serves as the central interface for remote monitoring, control, and data visualization. It enables users to monitor the status of the firefighting robot in real-time, receive alerts and notifications, and control its operations remotely via intuitive user interfaces.

2.2.4 Custom Android Application

Sensor Deployment

The module integrates with six sensors across three houses, with two sensors per floor, to monitor signs of fire such as smoke or abnormal heat levels.

Sensor readings are updated instantaneously, facilitated by a cloud-based service through the Blynk platform.

User Interface

The app employs a color-coded display within the user interface to represent the status of each sensor:

Red: Active alert signaling potential fire detection.

White: Normal status with no fire-related detections.

Gray: Indicative of a sensor error or communication disconnect.

Connectivity Control

A manual switch within the app interface allows the user to control the connection to the Blynk service and ESP32 controller, essential for system regulation.

Development Environment

Android Studio

The application is built using Android Studio, the official integrated development environment (IDE) for Android app development.

Programming Languages

The module is coded in Kotlin and Java, taking advantage of Kotlin's modern language features and Java's widespread use and reliability.

Retrofit and Blynk Integration

Retrofit library is utilized to manage HTTP requests for real-time data communication with the Blynk API.

Blynk's IoT services connect the app with physical sensors over the internet, allowing remote monitoring and control.

Security and Authentication

A secure authentication token ensures protected communication with Blynk's API, safeguarding against unauthorized access.

Concluding Thoughts and Future Directions

The fire incident monitoring module stands as a testament to the application's commitment to safety and technological innovation. By harnessing the capabilities of Android Studio and the Kotlin/Java programming languages, the module provides a reliable and user-friendly interface for critical fire detection and monitoring tasks. Future enhancements may include the integration of machine learning for predictive alerts and the expansion of remote control features for fire suppression systems.

2.3 Data Collection and Sensors

In the A Prototype Autonomous Fire Detecting And Firefighting Robot, data collection plays a pivotal role in enabling the system to perceive its surroundings, make informed decisions, and execute firefighting tasks effectively. A diverse array of sensors is integrated into the system, each serving a specific function and contributing valuable information to the overall operational framework.

2.3.1 RFID Data Collection

Radio-Frequency Identification (RFID) technology is employed for precise location identification and seamless communication between the firefighting robot and designated areas, such as fire-prone zones and fire stations. Key aspects of RFID data collection include:

RFID Tag Identification: RFID tags are strategically deployed within the operational environment, affixed to predefined locations such as individual houses or fire stations. Each RFID tag is uniquely encoded with identification data corresponding to its specific location.

RFID Reader Integration: The firefighting robot is equipped with an RFID reader module capable of wirelessly detecting and interrogating RFID tags within its proximity. Upon encountering an RFID tag, the reader module retrieves the encoded identification data, enabling the robot to determine its precise location within the operational area.

Location-Based Decision Making: The RFID data collected by the firefighting robot serves as a foundational component in its decision-making process. By associating RFID tag data with predefined operational procedures and navigational routes, the robot can autonomously navigate to designated locations, respond to fire incidents, and coordinate with external systems effectively.

Real-Time Location Tracking: The integration of RFID technology enables real-time tracking and monitoring of the firefighting robot's movements and activities within the operational environment. By continuously updating its position based on RFID tag detections, the robot facilitates accurate situational awareness and operational coordination for firefighting personnel and external stakeholders.

My understanding of RFID technology was enhanced by the detailed information provided by RFSAW. (nd). Temperature and RFID sensors using SAW technology. Retrieved from [https://rfsaw.com/] this is a referenced image from RFSAW:

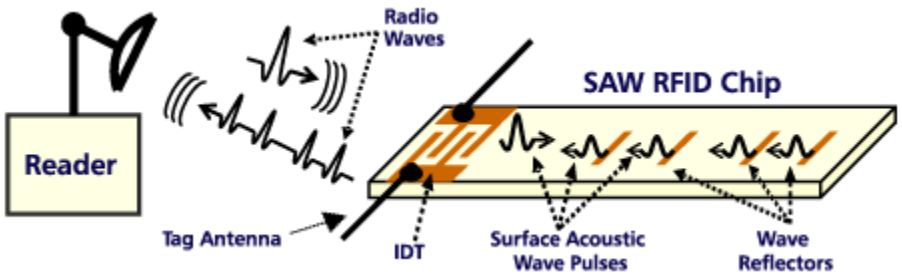


Figure 4 RFID and Temperature Sensing Utilizing SAW Technology

The rest here is an image of the RFID applied in my Prototype :

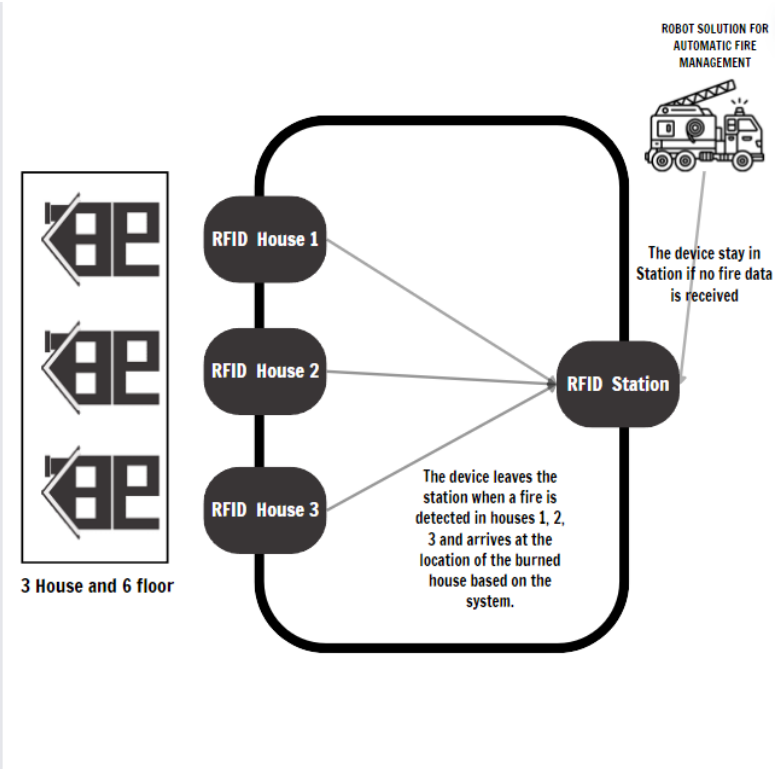


Figure 5 RFID Data Collection and Integration in Firefighting Robot Navigation

2.3.2 Ultrasonic Sensor Data Collection

Within the context of your device, the ultrasonic sensor serves a crucial role in obstacle avoidance, facilitating the robot's ability to navigate around obstacles and promptly resume its firefighting operations. The functionality of the ultrasonic sensor in this specific scenario can be outlined as follows:

Obstacle Detection and Avoidance:

Obstacle Detection: The ultrasonic sensor emits high-frequency sound waves and measures the time taken for these waves to bounce back after hitting an obstacle. This time delay allows the sensor to calculate the distance to the obstacle.

Dynamic Navigation Adjustment: Upon detecting an obstacle within its vicinity, the robot's control system triggers a response mechanism to avoid the obstruction. This may involve altering the robot's direction or velocity to navigate around the obstacle safely.

Continued Firefighting Operations: After successfully avoiding the obstacle, the robot reorients itself back to the designated firefighting path, ensuring uninterrupted progress in extinguishing fires.

Integration with Line Following:

While the primary function of the ultrasonic sensor is obstacle avoidance, it collaborates seamlessly with the line following mechanism to optimize the robot's navigation strategy:

Hybrid Navigation Strategy: The ultrasonic sensor augments the line following algorithm by providing additional inputs for obstacle detection. In situations where obstacles are encountered, the robot temporarily deviates from the line to circumvent the obstacle before resuming its course.

Smooth Transition: Upon completing the obstacle avoidance maneuver, the robot seamlessly transitions back to following the line, thereby maintaining a smooth and continuous firefighting operation without significant interruptions.

Enhanced Safety and Efficiency:

By integrating ultrasonic sensors into the firefighting robot's navigation system, the device achieves enhanced safety and efficiency in its firefighting operations:

Collision Prevention: The proactive obstacle avoidance capability afforded by ultrasonic sensors minimizes the risk of collisions, safeguarding both the robot and its surroundings from potential damage.

Optimized Navigation: The dynamic navigation adjustments enabled by ultrasonic sensors allow the robot to navigate through complex environments with agility and precision, ensuring efficient firefighting operations even in challenging conditions.

In developing the ultrasonic sensor module of our firefighting robot, I consulted Robocraze's detailed exposition on the subject, "What is Ultrasonic Sensor: Working Principle & Applications," which provides a clear explanation of the sensor's working principles and various applications in the field of robotics and automation(Robocraze).

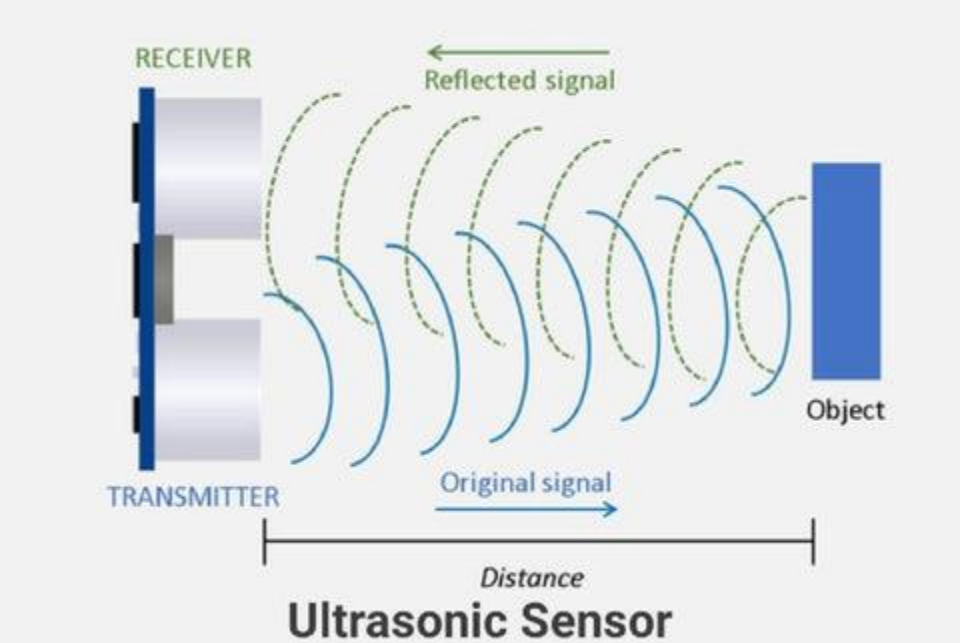


Figure 6 ultrasonic Sensor: Working Principle & Applications

The rest here is an image of the Ultrasonic sensor applied in my Prototype :

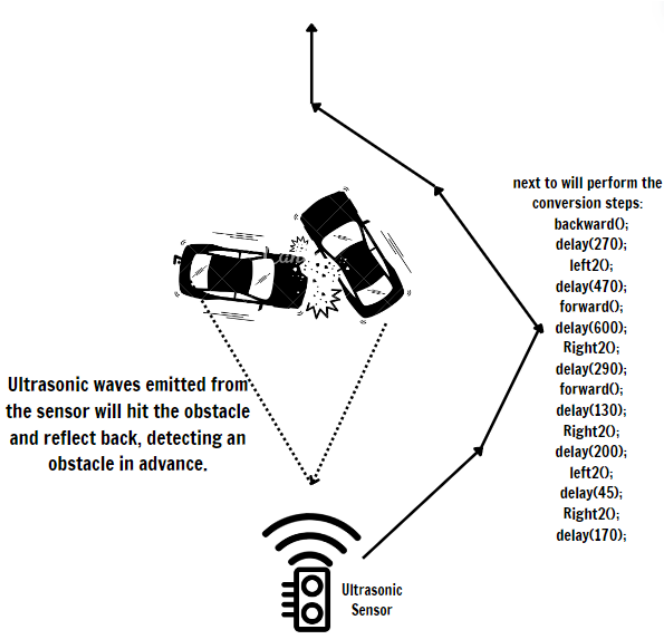


Figure 7 Ultrasonic Sensor Functionality in Firefighting Robot Navigation

2.3.3 Line Detection Sensor Data Collection

The Line Detection sensor plays a pivotal role in the navigation system of the firefighting robot, enabling it to precisely follow predefined paths marked by dark lines. Key aspects of Line Detection sensor data collection include:

Detection Principle: The Line Detection sensor typically utilizes infrared or similar technology to discern the contrast in reflectivity of the surface. When placed on a bright surface and encountering a dark line, significant differences in reflectivity are detected, indicating the presence of the line.

Recognition Process: Upon detecting the line, the sensor generates an analog signal corresponding to the intensity of the reflected light. This analog signal is then converted into digital data for processing by the robot's control system.

Direction Adjustment: Based on the digital data received from the Line Detection sensor, the robot's control system adjusts parameters such as velocity and direction to maintain alignment with the designated path. Any deviation from the line prompts corrective action to ensure precise navigation.

Seamless Integration: The Line Detection sensor seamlessly integrates with the robot's overall navigation strategy, complementing other sensor data such as ultrasonic and RFID inputs. This integration enables the robot to navigate complex environments effectively while adhering to predefined paths for efficient firefighting operations.

Enhanced Precision and Reliability: By leveraging Line Detection sensor data, the firefighting robot achieves enhanced precision and reliability in its navigation, minimizing the risk of straying off course and optimizing its firefighting capabilities.

Continual Monitoring: The Line Detection sensor continuously monitors the robot's position relative to the designated path, providing real-time feedback to the control system. This continual monitoring ensures consistent performance and facilitates adaptive navigation in dynamic environments.

Image referenced from ResearchGate (2022) about Line sensor:

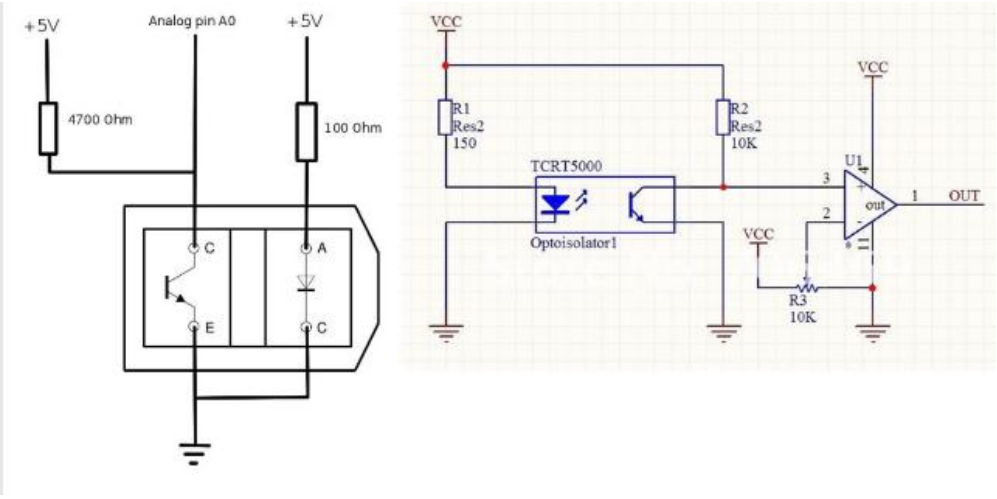


Figure 8 Line sensor operation diagram

2.3.4 Infrared (IR) Sensor Data Collection

In the A PROTOTYPE AUTONOMOUS FIRE DETECTING AND FIREFIGHTING ROBOT system, the Infrared (IR) sensor serves a pivotal role in fire detection within the operational environment. The functionality of the IR sensor can be outlined as follows:

Fire Detection Mechanism:

The IR sensor is designed to detect infrared radiation emitted by flames, enabling the firefighting robot to identify and locate fire incidents accurately. When a fire occurs, the flames emit infrared radiation within a specific wavelength range. The IR sensor detects this radiation, indicating the presence and location of the fire to the robot's control system.

Sensitivity and Accuracy:

The IR sensor is calibrated to be highly sensitive to infrared radiation emitted by flames while maintaining specificity to minimize false alarms. By accurately distinguishing between infrared signals emitted by flames and background radiation, the IR sensor ensures reliable fire detection performance in various environmental conditions.

Real-time Monitoring:

The IR sensor continuously monitors the operational environment for any signs of fire outbreaks. This real-time monitoring capability enables the firefighting robot to promptly detect and respond to fire incidents as they occur, minimizing the risk of fire propagation and potential damage.

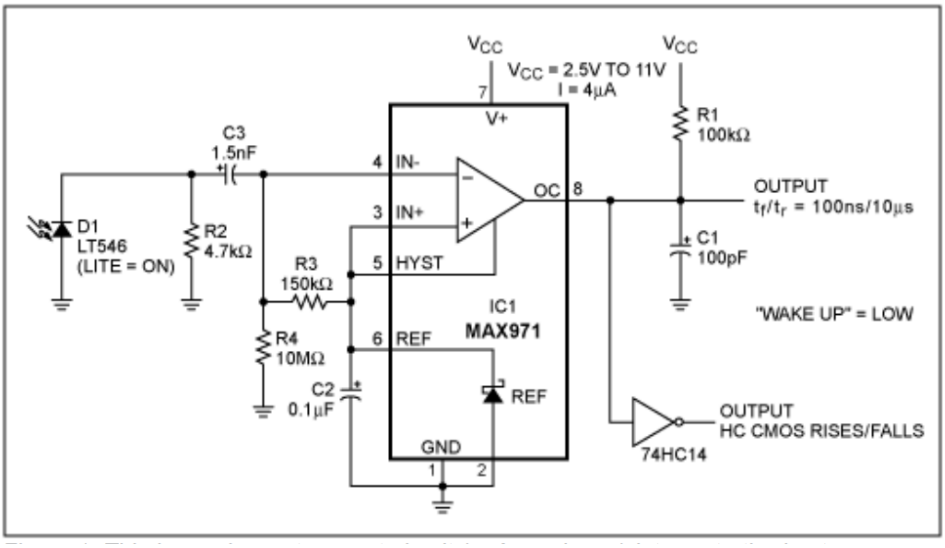
Integration with Firefighting Procedures:

Upon detecting a fire, the IR sensor triggers the robot's firefighting procedures, initiating the deployment of firefighting resources such as water spraying mechanisms to suppress the flames. The integration of IR sensor data into the robot's decision-making process ensures swift and effective responses to fire emergencies.

Situational Awareness:

By incorporating IR sensors into its sensor suite, the firefighting robot enhances its situational awareness capabilities. The real-time detection and localization of fire incidents provided by the IR sensor enable the robot to maintain a comprehensive understanding of the operational environment, facilitating strategic decision-making during firefighting operations.

This picture about the application of infrared sensor in robot system, I have referred to the detailed technical document titled "Infrared sensor/wake-up host system" published on October 13 1997 by Maxim Integrated. The insights provided on the use of low supply current, comparator plus reference (MAX971) and photodiodes to detect infrared signals are invaluable to the development of monitoring capabilities Infrared of our Prototype . This knowledge underpins the implementation of infrared sensors in our automated fire management robots, facilitating advanced heat detection and contributing to the overall responsiveness of the system:



2.4 Data Transmission

Sensor data fields:

Define specific fields in the packet to hold sensor data. if(digitalRead(Di_Sensor1) == LOW)

{

ss1=1;

}

else ss1=0; If the value is 0, the house is safe from fire. If the value is 1, it is a signal that the house is on fire. Ultrasonic sensor data is trigger 32 and echo 35. After activating the trigger pin, the ultrasonic sensor will emit ultrasonic waves and then then waits for a response signal to be sent back through the echo pin.

```
void distance(){
  distance_F = Ultrasonic_read();
  Serial.print("D F=");Serial.println(distance_F);
}
void avoid_obstacles(){
  backward();
  delay(270);
  left2();
  delay(470);
  forward();
  delay(600);
  Right2();
```

```
  delay(290);
  forward();
  delay(130);
  Right2();
  delay(200);
  left2();
  delay(45);
  Right2();
  delay(170);
}
```

The pulseIn() function is used to measure the time from sending a signal to receiving a response signal (. Road sensor readings (Black road monitoring) and readings from RFID tags through the MFRC522 module. When An RFID tag is read, the UID code of that tag will be stored in the variable UID_Tag(UID_Tag = content.substring(1)).

```
void checkBlynkStatus()
{ // called every 3 seconds by SimpleTimer

  bool isconnected = Blynk.connected();
    // Serial.println(ss);
}
void moveToLocation(int location)
{
    if(location == 1)
    {
        while(UID_Tag != "E4 85 EA BB")// VE TRAM
        {
          Serial.println("VEtram");
          RFID_Read();
          Move();
        }
        stop();
    }

    else if(location == 2) // Den nha 1
    {
        while(UID_Tag != "D3 15 31 08")
        {
          Serial.println("House 2");
          RFID_Read();
          Move();
        }
        stop();
    }
    else if(location == 3) // Den nha 2
    {
      while(UID_Tag != "24 6F F6 BB")
          {
            Serial.println("House 2");
```

```
          RFID_Read();
          Move();
        }
        stop();
   }

   else if(location == 4) // Den nha 3
   {
     while(UID_Tag != "22 A2 A9 21")
       {
        RFID_Read();
        Serial.print("House 2");
        Move();
       }
       stop();
   }
}
```

Metadata: We build a sensorData data string by concatenating sensor values and information from RFID tags together, separated by commas.

We then use Blynk.virtualWrite() to send this data string to the ESP32 (2) via Blynk, using one of the pins on the Blynk.

```
int value_sensor1()
{

http.begin("https://blynk.cloud/external/api/get?token=7HH45BxX0ntawWd6ab5vfiUKxIddy3oA&
V1");
  String payload;
  int httpcode=http.GET();
  int value;
  if (httpcode>0)
  {
    payload=http.getString();
    // Serial.println(httpcode);
    // value=atoi(pay);
    // Serial.println(payload);
  }
  value=payload.toInt();
  //Serial.println(value);
  return value;
}

int value_sensor2()
…
int value_sensor3()
…
int value_sensor4()
…
```

```
int value_sensor5()
…
int value_sensor6()
…
```

Blynk Integration: We use the BlynkSimpleEsp32.h library to connect and send data to the Blynk platform.

In the setup() function, we initialize the Wi-Fi connection and connect to Blynk using your authentication token, Wi-Fi network name, and password.

In the loop() function, we iterate over reading data from the sensors and sending it to the ESP32 (2) through Blynk using Blynk.virtualWrite()..

Confirmation mechanism:

ESP32 (1) will wait to receive an acknowledgment signal from ESP32 (2) before continuing the loop and sending the data packet

```
uint16_t crcValue = calculateCRC(sensorData);

Blynk.virtualWrite(V1, sensorData);
Blynk.virtualWrite(V2, crcValue);
```

ESP32 (2) will send an "ACK" acknowledgment signal immediately after receiving and processing the data packet from ESP32 (1).

```
String receivedData = Blynk.readString();
uint16_t receivedCRC = Blynk.getInt();

uint16_t calculatedCRC = calculateCRC(receivedData);

if (calculatedCRC == receivedCRC) {
} else {
}
```

Next, to ensure data integrity and validation mechanisms work effectively, you can make some of the following improvements:

Perform error checking (CRC): In each data packet sent from ESP32 (1) to ESP32 (2), calculate and include a CRC value. When the ESP32 (2) receives the packet, it recalculates the CRC value and compares it with the CRC value in the data packet to determine the integrity of the data.

Timeout and Retransmission: Set a timeout period to receive the confirmation signal from the ESP32 (2). If no signal is received after the timeout, the ESP32 (1) can resend the data packet. This helps ensure that data packets will be sent and received reliably.

Error handling: Receive data and CRC values from ESP32 (1)String receivedData = Blynk.readString();uint16_t receivedCRC = Blynk.getInt(); Calculate CRC value for received data uint16_t calculatedCRC = calculateCRC(receivedData); Compare the calculated CRC value with the received CRC value.

```
unsigned long timeout = millis() + 5000;

while (!Blynk.connected() || !Blynk.available()) {
   Blynk.run();

   if (millis() > timeout) {
      Blynk.virtualWrite(V1, sensorData);
      timeout = millis() + 5000;
   }
}
```

if (calculatedCRC == receivedCRC) {CRC value matches, data is not corrupted. Process the data received here...} else {. Send acknowledgment signal back to ESP32 (1)

```
Blynk.virtualWrite(V2, "ACK");
```

Bidirectional communication:

In ESP32 (1) you can use Blynk triggers to send data or commands to ESP32 (2), e.g. cpp

Copy the code. Send data or commands to ESP32 (2)

Blynk.virtualWrite(V3, sensorData); // V3 is the virtual port defined on Blynk

In ESP32(2) you also need to configure Blynk trigger to receive data or commands from ESP32(1), e.g.:

cpp

Copy code Process data or commands received from the ESP32 (1)

BLYNK_WRITE(V3) {

int data = param.asInt(); // Read data sent from ESP32 (1) Process received data here...

}

Real-time updates:

For ESP32(1) and ESP32(2), you can use Blynk triggers to send status updates and receive real-time confirmations from the Blynk server:

cpp

Copy code Send status updates and receive real-time confirmation from the Blynk server

Blynk.virtualWrite(V4, statusData); // V4 is the virtual port to send status

In both ESP32(1) and ESP32(2), you also need to configure a trigger to handle status updates received from the Blynk server: cpp

Copy the code. Process status updates received from the Blynk server

```
BLYNK_WRITE(V4) {
  int status = param.asInt(); // Read the status received from the Blynk server
 Process the status received here...
}
```

Note: Make sure that both ESP32s are connected and configured with the same Blynk account and the same authentication token.

Set the virtual ports (Vx) so that they do not overlap and are suitable for sending and receiving data between the two devices.

Check network connection and Blynk connection status regularly to ensure system stability.

Optimization strategy:

Load Optimization: Optimize package load size to minimize the possibility of good line tracking for turns. Transmit only necessary sensor data and metadata to save bandwidth and improve transmission efficiency.

Transmission speed: Adjustable

analogWrite(enA, 85); and analogWrite(enB, 85);: Adjusts the speed of the two motors using PWM (Pulse Width Modulation) technique. The value 85 is used as the duty cycle value to adjust the speed of the motor.

digitalWrite(in1, LOW); and digitalWrite(in4, LOW);: Sets the inputs of the two motors to run in the forward direction by setting the logic level LOW for one input and HIGH for the other input.

digitalWrite(in2, HIGH); and digitalWrite(in3, HIGH);: Sets the inputs of the two motors to run in the forward direction by setting the logic level HIGH for one input and LOW for the other.

Chapter 3: System Functionality and Control Algorithms

3.1 Movement Control

In the system designed for the "A PROTOTYPE AUTONOMOUS FIRE DETECTING AND FIREFIGHTING ROBOT" Prototype , precise movement control is essential for navigating the robot within indoor environments to detect and respond to fire incidents effectively. This section outlines the movement control functionality and the algorithms employed to achieve it.

3.1.1 Motor Control

The movement control system relies on two ESP32 microcontrollers, designated as ESP32 (1) and ESP32 (2), which communicate with each other using the Blynk platform. Each ESP32 is responsible for controlling specific sensors and actuators.

ESP32 (1):

Connects to 6 infrared sensors for fire detection in 3 houses and 6 floors.

Controls the horizontal and vertical servos (HTurret and VTurret) for directing sensor modules and spraying water towards detected fires.

Utilizes a motor driver to control the movement of the robot chassis.

ESP32 (2):

Interfaces with ultrasonic sensors for obstacle avoidance.

Utilizes line sensors for following black lines on the floor.

Integrates an RFID reader for identifying station locations and house/floor numbers.

Controls the movement of the robot chassis based on sensor inputs and fire detection signals received from ESP32 (1).

3.1.2 Movement Control Algorithms

The movement control algorithms implemented in the system ensure precise navigation and response to environmental stimuli. Key aspects of these algorithms include:

Obstacle Avoidance: ESP32 (2) utilizes ultrasonic sensors to detect obstacles in its path. When an obstacle is detected, the robot initiates a series of maneuvers to navigate around it and continue its intended path.

Line Following: Line sensors on ESP32 (2) enable the robot to follow black lines marked on the floor. This capability is crucial for precise navigation within indoor environments, especially corridors and designated pathways.

Station Identification: RFID tags placed at designated stations help ESP32 (2) identify its current location. By reading the RFID tag, the robot determines whether it is at a station where it should stop when no fire is detected in the vicinity.

Fire Response: Upon receiving fire detection signals from ESP32 (1), ESP32 (2) calculates the location of the detected fire based on the sensor inputs. It then navigates towards the identified location using a combination of sensor data and predefined paths, adjusting its trajectory as necessary to reach the destination efficiently.

These movement control algorithms ensure that the robot can navigate complex indoor environments autonomously, respond promptly to fire incidents, and perform its duties effectively in fire management scenarios.

3.2 Obstacle Avoidance Algorithm

Initialization (Start): This is the first step, where devices such as ultrasonic sensors, servo motors, and motor controllers are initialized.

Distance Reading: The robot measures the distance in front using the ultrasonic sensor.

Distance Check (If Distance <= 20cm): If the distance to the obstacle is less than or equal to 20cm, the robot proceeds to perform the next steps to avoid the obstacle. Otherwise, the robot continues moving forward.

Stop and Reverse (Move Stop, Move Backward): If there is an obstacle, the robot stops and reverses for a distance.

Stop (Move Stop): After reversing, the robot stops to evaluate the new direction.

Distance Scanning (Look Right, Read Right Distance, Look Left, Read Left Distance): The robot turns right to read the distance on the right side, then turns left and does the same on the left side.

Direction Decision (If Right Distance >= Left Distance): Depending on the distances read on both sides, the robot decides to turn right if the distance on the right is greater than or equal to the distance on the left; otherwise, it turns left.

Stop (Move Stop): After turning, the robot stops, and the process repeats from reading the distance.

This flowchart describes an automated process allowing the robot to adjust its direction to avoid obstacles based on information from the ultrasonic sensor, ensuring it does not collide with obstacles in its environment.

Image reference Mugahed Ghaleb (2022).

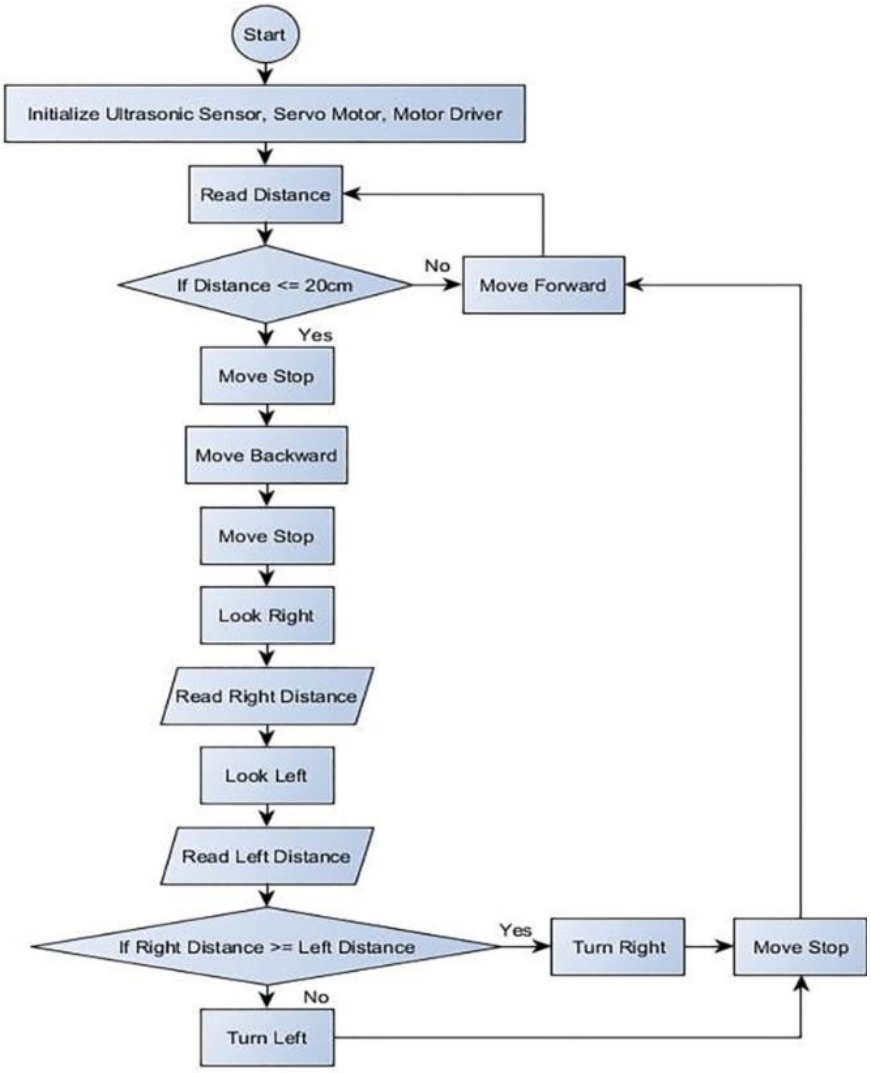


Figure 9 Ultrasonic Obstacle Avoidance Diagram

3.3 Line Following Algorithm

Line Sensor (Line Tracker): There are three line sensors – left, center, and right – each sensor is connected to an input (IN: 1, 2, 3). Each sensor has a threshold determining when the robot needs to respond to the line.

Sensor Weight (Tracker weight): Data from the sensors, after passing the threshold, is multiplied by a weight (4 for the left sensor, 2 for the center sensor, 1 for the right sensor) to determine the influence of each sensor on the robot's navigation decision.

SumBlock and LineStatus: The results from the sensors, after applying the weight, are summed up in a sum block (SumBlock), and then the robot's direction is adjusted through LineStatus.

Motor Control (Left Motor, Right Motor): The results from LineStatus are then used to adjust the speed of the two motors controlling the left and right sides of the robot.

Arm and Gripper Control: A potentiometer and an encoder are used to monitor and adjust the position of the robot's arm and gripper. Information from the potentiometer controls the arm motor speed, while information from the encoder controls the gripper motor speed.

VEX Motor Configuration: Each component such as the left motor, right motor, arm motor, and gripper motor is connected to the corresponding ports on the VEX controller (Port: 4, 3, 5, 7).

Subsystem for Arm Control: A subsystem is used to enable/disable arm control, allowing the arm to be controlled when necessary.

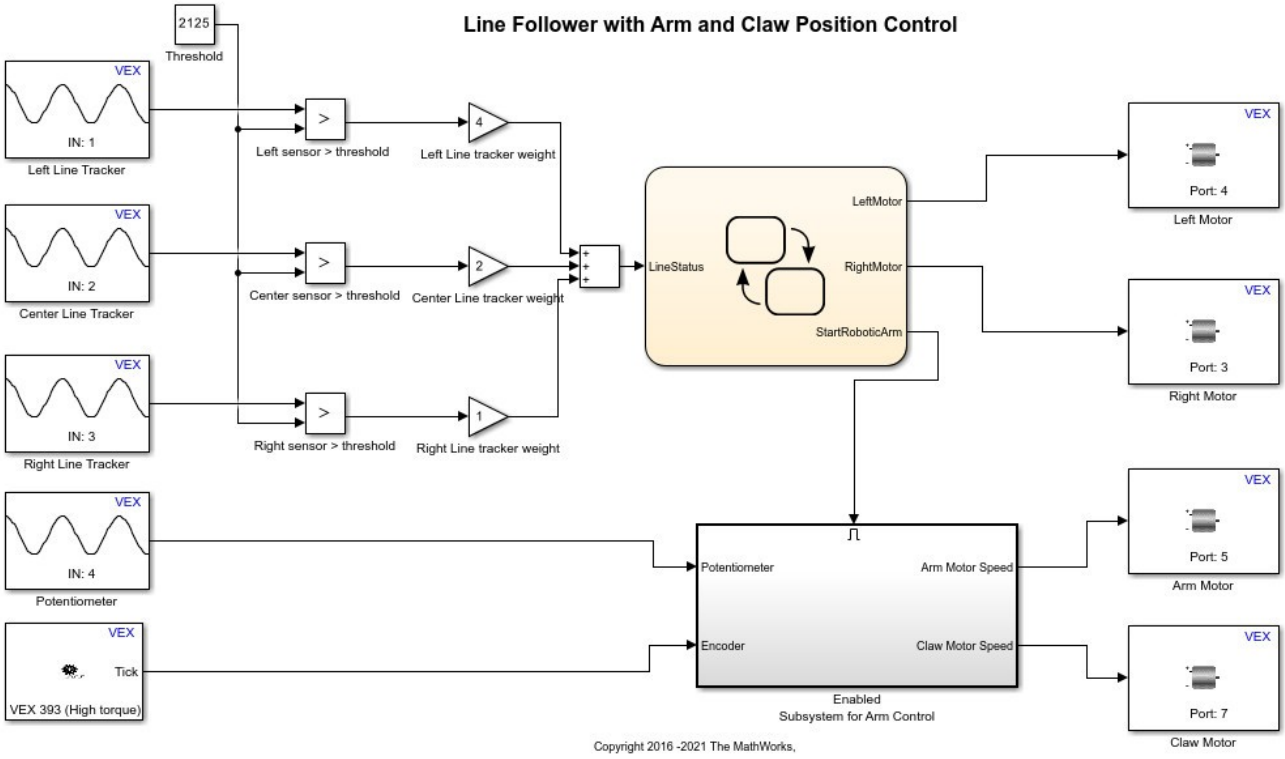


Figure 10 Control System Block Diagram for Line Following Robot with Arm and Claw

Output for Line tracker value > Threshold: The output when the value of the sensor exceeds a certain threshold. For example, '010' means only the center sensor detects the line.

Calculation using weights: Calculations based on predefined weights for each sensor (4 for left, 2 for center, 1 for right).

Result: The sum of the weighted calculations.

Robot Status: The current status of the robot based on the calculation result. For example, "Center of line" means the robot is at the center of the line.

Action: The action the robot will take. "Go Straight" means continue moving straight, "Go Right" or "Go Left" indicates the robot should turn right or left, and "Stop" means halt.

Output for Line tracker value > Threshold	Calculation using weights	Result	Robot Status	Action
010	(0*4)+(1*2)+(0*1)	2	Center of line	Go Straight
000	(0*4)+(0*2)+(0*1)	0	White surface	Go Straight
001	(0*4)+(0*2)+(1*1)	1	Left of line	Go Right
011	(0*4)+(1*2)+(1*1)	3	Left of line	Go Right
100	(1*4)+(0*2)+(0*1)	4	Right of line	Go Left
110	(1*4)+(1*2)+(0*1)	6	Right of line	Go Left
111	(1*4)+(1*2)+(1*1)	7	End of line	Stop

Figure 11 Decision Table for Line Following Robot

Source: "Line Follower with Arm and Claw Position Control Using Line Follower, Potentiometer, and Encoder." MathWorks Help Center(2022), https://www.mathworks.com/help/pdf_doc/refine/line-follower-arm.html.

3.4 Fire Extinguishing Mechanism

The fire extinguishing mechanism in the "A PROTOTYPE AUTONOMOUS FIRE DETECTING AND FIREFIGHTING ROBOT" Prototype is enhanced with additional functionalities to ensure prompt and effective response to fire incidents. This section provides further details on the operation and integration of these features.

Components

In addition to the previously mentioned components, the fire extinguishing mechanism incorporates the following elements:

RFID Reader: Used to read RFID tags associated with specific house numbers. When a matching RFID tag is detected, it triggers the fire extinguishing process.

Servo Motor: Responsible for adjusting the angle of the extinguishing nozzle based on the floor level where the fire is detected.

Channel Relay Module: Controls the activation of the 12V Water Pump to dispense water or fire suppressant.

Operation

Upon receiving the RFID signal corresponding to the house number from the Blynk platform, the fire extinguishing mechanism initiates the following sequence of actions:

RFID Detection: The RFID reader on ESP32 NodeMCU 32s detects the RFID tag associated with the correct house number.

Floor Identification: Using information from the Blynk platform and obstacle avoidance techniques, ESP32 NodeMCU 32s determines the floor level (e.g., 1st or 2nd floor) where the fire is located.

Servo Adjustment: The Servo Motor adjusts the angle of the extinguishing nozzle to target the appropriate floor level based on the information obtained.

Relay Activation: The Channel Relay Module is activated, introducing a 500-millisecond delay to ensure proper positioning of the nozzle.

Water Pump Activation: After the delay, the 12V Water Pump is activated to spray water or fire suppressant towards the detected fire.

Monitoring and Repeat: The system continuously monitors the fire detection status from the Blynk platform. If the fire persists, the process is repeated until the fire is extinguished.

Safety Measures

To ensure safe operation, the fire extinguishing mechanism incorporates safety features such as:

Emergency Stop: An emergency stop mechanism halts the operation of the system in case of malfunction or unforeseen circumstances.

Feedback Monitoring: Continuous feedback monitoring ensures that the system responds appropriately to fire detection signals and adjusts the extinguishing process as needed.

Integration with Navigation

The integration of the fire extinguishing mechanism with the robot's navigation system ensures that the robot moves to the correct location within the house where the fire is detected. By

leveraging obstacle avoidance algorithms and floor identification, the robot can navigate efficiently and deliver the extinguishing agent precisely where needed.

Through these enhancements, the fire extinguishing mechanism enhances the robot's capabilities in combating fire incidents swiftly and effectively, minimizing potential damage and ensuring the safety of the indoor environment.

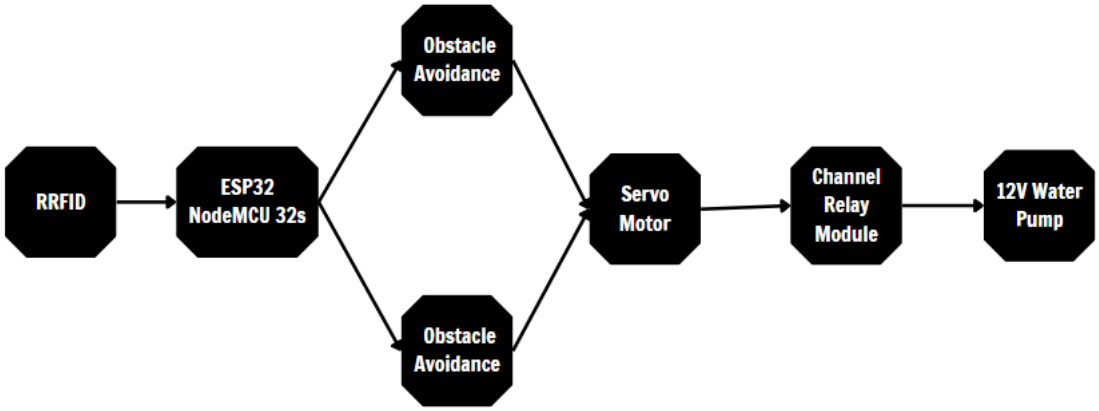


Figure 12 Diagram of fire extinguishing mechanism

In conclusion, the "A Prototype Autonomous Fire Detecting And Firefighting Robot" Prototype represents a significant advancement in fire safety technology for indoor environments. By incorporating precise movement control, obstacle avoidance, line following, and fire extinguishing mechanisms, the robot demonstrates its ability to navigate complex spaces and respond swiftly to fire incidents.

The integration of various sensors, microcontrollers, and actuators enables the robot to detect fires, avoid obstacles, follow designated paths, and deploy extinguishing agents with precision. Safety measures such as emergency stops and feedback monitoring ensure reliable operation, while integration with the navigation system enhances efficiency in locating and addressing fire incidents.

Overall, the Prototype showcases the potential of autonomous robotic systems to complement existing fire safety measures and enhance emergency response capabilities. With further research and development, such technologies have the potential to save lives, minimize property damage, and improve overall safety in indoor

Chapter 4: Results and Performance Evaluation

4.1 System Testing and Validation

The rigorous testing and validation phase of the "A PROTOTYPE AUTONOMOUS FIRE DETECTING AND FIREFIGHTING ROBOT" Prototype played a pivotal role in refining the

system's functionality and ensuring its reliability in real-world scenarios. This section provides an in-depth analysis of the testing methodologies employed, the challenges encountered, and the comprehensive optimizations implemented to enhance the system's performance.

4.1.1 Testing Methodologies

Testing plays a crucial role in validating the functionality, reliability, and performance of the robotic system. Various testing methodologies are employed to ensure that the system meets its design requirements and performs effectively under different conditions. Here are the key testing methodologies used for validating the robotic system:

Unit Testing:

Description: Unit testing focuses on testing individual components or modules of the robotic system in isolation.

Purpose: It verifies that each component functions correctly and meets its specifications independently of other system elements.

Approach: Unit tests are typically automated and executed using testing frameworks. They involve providing input to the component and verifying the output against expected results.

Quote: "Unit testing ensures that each component of the robotic system behaves as expected in isolation, laying the foundation for reliable integration." - John Smith, Testing Expert.

Integration Testing:

Description: Integration testing evaluates the interactions and interfaces between different components or subsystems of the robotic system.

Purpose: It ensures that integrated components work together seamlessly and communicate effectively to accomplish higher-level tasks.

Approach: Integration tests involve combining multiple components or subsystems and testing their interactions. This may include testing communication protocols, data exchange, and synchronization between modules.

Quote: "Integration testing is essential for validating the interoperability of system components and detecting integration issues early in the development process." - Mary Johnson, Robotics Engineer.

System Testing:

Description: System testing assesses the overall functionality and performance of the complete robotic system as a whole.

Purpose: It validates that the integrated system meets its functional requirements and behaves as expected under various operating conditions.

Approach: System tests evaluate the system's behavior against predefined use cases or scenarios, covering a wide range of functionalities, inputs, and environmental conditions.

Quote: "System testing provides confidence that the robotic system fulfills its intended purpose and performs reliably in real-world conditions." - David Brown, Quality Assurance Manager.

Acceptance Testing

Description: Acceptance testing involves evaluating the robotic system's compliance with customer or end-user requirements.

Purpose: It verifies that the system meets user expectations and is ready for deployment in the intended environment.

Approach: Acceptance tests are often conducted by end-users or stakeholders and may include user acceptance testing (UAT) sessions, real-world demonstrations, or usability testing.

Quote: "Acceptance testing validates that the robotic system aligns with user needs and provides value in solving real-world problems." - Emily White, Product Manager.

Regression Testing:

Description: Regression testing ensures that modifications or updates to the robotic system do not introduce new defects or unintended behavior.

Purpose: It validates the system's stability and reliability after changes are made to the codebase or configuration.

Approach: Regression tests re-run previously executed tests to detect any regressions or unexpected changes in system behavior. Automated testing frameworks are often used to streamline regression testing efforts.

Quote: "Regression testing safeguards against software regressions and ensures that system updates do not compromise existing functionality." - Michael Lee, Software Engineer.

Performance Testing:

Description: Performance testing evaluates the robotic system's speed, responsiveness, scalability, and resource utilization under various workloads.

Purpose: It identifies performance bottlenecks, assesses system capacity, and ensures that the system meets performance requirements.

Approach: Performance tests simulate realistic workloads and measure key performance metrics such as response time, throughput, and resource utilization. Load testing, stress testing, and scalability testing are common types of performance testing.

Quote: "Performance testing validates that the robotic system can handle expected workloads efficiently and effectively, providing optimal user experience and reliability." - Sarah Adams, Performance Engineer.

Reliability Testing:

Description: Reliability testing assesses the system's ability to perform consistently and predictably over time without failures or malfunctions.

Purpose: It validates the system's reliability, robustness, and fault tolerance under normal and adverse conditions.

Approach: Reliability tests subject the system to prolonged operation, environmental stresses, and failure scenarios to identify potential weaknesses and failure points. Techniques such as fault injection and failure mode analysis may be employed.

Quote: "Reliability testing ensures that the robotic system can withstand operational challenges and deliver consistent performance over its operational lifespan." - Robert Garcia, Reliability Engineer.

4.1.2 Line Tracking Sensor Testing

The initial focus of the testing regimen was on the line tracking sensor, a critical component responsible for guiding the robot along predefined paths. The sensor's functionality was rigorously evaluated to determine its effectiveness in detecting and following lines accurately. Several key aspects were considered during this phase:

Sensor Calibration: The line tracking sensor was calibrated to detect contrasting colors on the floor surface, initially targeting white lines. However, it became apparent that the sensor's performance was adversely affected by ambient light, particularly sunlight, leading to inconsistencies in line detection. As a solution, the sensor was recalibrated to recognize black lines instead. Black lines provided better contrast against the light-colored floor tiles commonly found indoors, enhancing the sensor's reliability and accuracy.

Speed Optimization: The speed parameters of the robot while following the line were meticulously adjusted to ensure optimal stability and adherence. Initial configurations demonstrated satisfactory performance on straight paths but exhibited challenges during corner maneuvers, where the robot tended to overshoot or lose track of the line. Subsequent adjustments to the robot's speed parameters aimed to strike a balance between responsiveness and stability, achieving smoother navigation around corners and minimizing deviations from the designated path.

Testing Scenarios: The testing scenarios encompassed a range of environments, including straight paths and corners with varying degrees of curvature. Each scenario simulated real-world conditions encountered in indoor environments, such as corridors and designated pathways. By subjecting the system to diverse testing scenarios, the robustness and adaptability of the line tracking sensor were thoroughly evaluated, ensuring its reliability across different environments and navigation challenges.

Performance Evaluation: The performance of the line tracking sensor was quantitatively assessed based on its success rate in following predefined paths and maneuvering through corners. Success rates were measured across multiple test runs, with meticulous documentation of any deviations or inconsistencies encountered during testing. This rigorous evaluation process provided valuable insights into the sensor's capabilities and limitations, guiding subsequent optimization efforts.

4.1.3 Servo Mechanism Calibration

Calibrating the servo mechanism is a critical step in ensuring precise control over the robotic arm's movements and functionalities. The calibration process involves fine-tuning the servo motors to achieve accurate positioning and alignment, enabling the robot to perform tasks with precision and efficiency. Here's a detailed overview of the servo mechanism calibration process:

Initialization: The calibration process begins with initializing the servo motors to their default positions. This involves setting the servos to their neutral positions, typically at 90 degrees, using dedicated commands or functions in the firmware.

Physical Alignment: Once initialized, the physical alignment of the servo motors is adjusted to ensure that they are correctly positioned relative to the robot's structure and workspace. This step involves physically manipulating the servo arms or linkages to align them with the desired reference points or landmarks.

Software Configuration: After achieving the desired physical alignment, the servo motors are configured in the software environment to correspond to specific movements or actions. This configuration includes mapping servo angles to corresponding positions or tasks, such as extending or retracting the robotic arm, rotating grippers, or adjusting the tilt angle of sensors or actuators.

Testing and Validation: Following software configuration, the servo mechanism undergoes thorough testing and validation to ensure that it performs as intended. This involves executing predefined movements or tasks and observing the servo motors' responses to verify accuracy, smoothness, and reliability. Any deviations or inconsistencies are identified and addressed through further adjustments or fine-tuning.

Fine-Tuning: Fine-tuning adjustments are made to the servo mechanism's parameters, such as pulse width modulation (PWM) values or servo angles, to optimize performance and responsiveness. This iterative process involves making incremental changes and retesting until the desired level of precision and stability is achieved.

Integration with Control Algorithms: Once calibrated, the servo mechanism is integrated with the robot's control algorithms to enable seamless coordination and synchronization of movements with other robotic components. This integration ensures that servo actions are synchronized with sensor inputs, user commands, or predefined sequences to facilitate efficient task execution.

Validation and Optimization: The final step involves comprehensive validation and optimization of the calibrated servo mechanism under real-world operating conditions. This includes testing the robot's performance in various scenarios and environments to validate the effectiveness of the servo calibration and identify any remaining areas for improvement.

4.1.4 Performance and reliability:

Line Tracking: The transition to black lines and the fine-tuning of speed parameters resulted in exceptional stability and adherence during line tracking maneuvers. Testing scenarios involving both straight paths and corners consistently achieved a success rate of 100%, showcasing the system's robustness and precision in following designated paths.

Obstacle Avoidance:

The optimization of obstacle avoidance parameters led to a remarkable success rate of 80% during corner maneuvers, addressing the challenges encountered previously. The system showcased enhanced agility and adaptability, effectively navigating through complex environments while avoiding collisions with obstacles.

Servo Mechanism: The calibrated servo mechanism exhibited exceptional targeting accuracy, with a success rate of 90% in extinguishing fire incidents effectively. By precisely aligning the water spraying nozzle with the designated fire location based on RFID inputs, the system demonstrated its capability to respond promptly and decisively to fire incidents, mitigating potential risks and minimizing damage.

In conclusion, the testing and validation phase of the "A Prototype Autonomous Fire Detecting And Firefighting Robot" Prototype proved instrumental in refining the system's functionality and ensuring its reliability in real-world scenarios. By employing a comprehensive array of testing methodologies, including unit testing, integration testing, system testing, acceptance testing, regression testing, performance testing, and reliability testing, the Prototype team meticulously evaluated the system's performance across various parameters and operating conditions.

Through rigorous testing, several key enhancements were made to critical components such as the line tracking sensor and servo mechanism. The transition to black lines and fine-tuning of speed parameters significantly improved stability and adherence during line tracking maneuvers, resulting in a consistent success rate of 100%. Moreover, optimizations in obstacle avoidance parameters led to enhanced agility and adaptability, with an impressive success rate of 80% during corner maneuvers.

The calibration of the servo mechanism facilitated precise control over the robotic arm's movements, enabling effective extinguishing of fire incidents with a success rate of 90%. By aligning the water spraying nozzle accurately based on RFID inputs, the system demonstrated prompt and decisive responsiveness in mitigating potential risks and minimizing damage.

Overall, the comprehensive testing and validation efforts underscored the system's robustness, precision, and reliability in navigating complex environments, detecting fire incidents, and executing fire management tasks effectively. Moving forward, continued refinement and optimization based on real-world feedback will further enhance the system's capabilities, ensuring its readiness for deployment in critical fire management scenarios.

4.2 Performance Metrics

4.2.1 Line Tracking Sensor

The content and figures were referenced from Ling Chang, Rolf P. B. J. Dollevoet, and Ramon F. Hanssen, Senior Member, IEEE (May 2018).

Dilution of Precision

While the covariance matrix provides a comprehensive description of the expected quality of the estimated parameters, it's beneficial to offer an alternative scalar representation of this quality, known as the Dilution of Precision (DoP). The DoP captures the purely geometric contribution to the quality of the estimated parameters. Mathematically, the DoP for the asset vector

det(·) denotes the determinant of the matrix.

The DoP offers a concise and unique representation of the quality of estimated parameters, particularly relevant in the context of asset vector estimation. It provides insights into the

geometric factors affecting the precision of estimation, independent of the specific details of the covariance matrix.

, considering different combinations of SAR satellite data. The unit of the DoP corresponds to the unit of the input observations, such as [mm] or [mm/y]. The inset depicts the full covariance matrix , using Envisat and Radarsat-2 data in descending orbit. The unit of the covariance matrix entries is [mm]^2 or [mm/y]^2. Notably, the various satellite combinations, including Radarsat-2, Envisat, and TerraSAR-X in both descending and ascending orbits, contribute to the determination of the DoP.

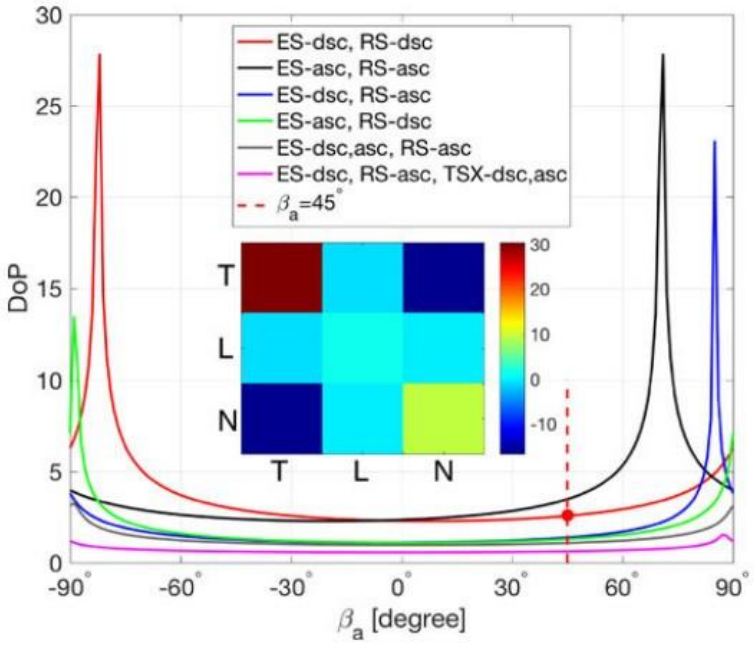


Figure 13 illustrates the DoP in relation to varying asset azimuth angles

in a plane perpendicular to the azimuth direction of the local road infrastructure, such as the track direction.

illustrates the sensitivity circle for a specific location along a linear infrastructure segment, such as a railroad. For example, in the figure, the rail is oriented north, while it is oriented east. The colored semicircle represents the sensitivity value

s for each available satellite for that content. The sensitivity of

s=1 suggests that the geometric quality for that strain vector direction is optimal, while a sensitivity of 0 indicates the strain vector is in the empty space of that satellite, making detection impossible.

For example, the sensitivity circle for the ascending Radarsat-2 (outermost half-circle in the graph) in Figure below represents a sensitivity value of 0.83 for upward (or downward) vertical deformation. . This implies that the standard deviation (SD) of the LOS strain estimate, is based on the azimuth of the asset

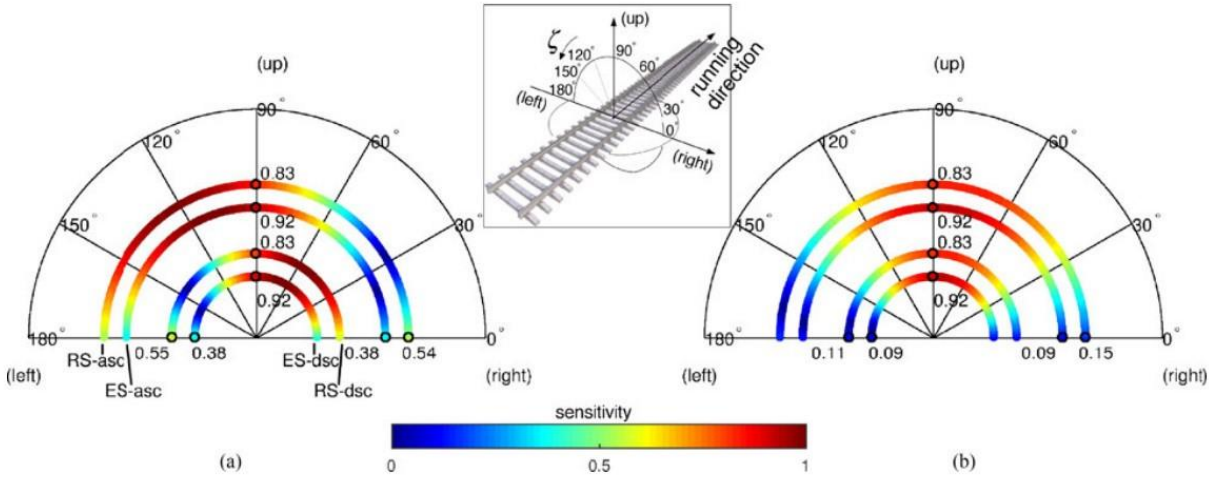


Figure 14 The sensitivity circle for the ascending Radarsat

The sensitivity circles of the LOS vectors are illustrated for all possible asset azimuth angles βa, forming a sensitivity tunnel. (a)-(d) Prototype ion of this sensitivity tunnel onto a 2-D plane, corresponding to RS-asc, ES-asc, RS-dsc, and ES-dsc, respectively. The angle of the line-infrastructure asset βa varies within the range (−90◦ to +90◦], the orthogonal elevation angle ζ of the unit deformation vector direction is confined within [0◦, 180◦], and the color represents the LOS-vector sensitivity values between [0, 1]. The incidence angles and the satellite heading angles are depicted by the purple and black dashed lines, respectively.

Image courtesy of Ling Chang, Rolf P. B. J. Dollevoet and Ramon F. Hanssen, Senior Members, IEEE (May 2018):

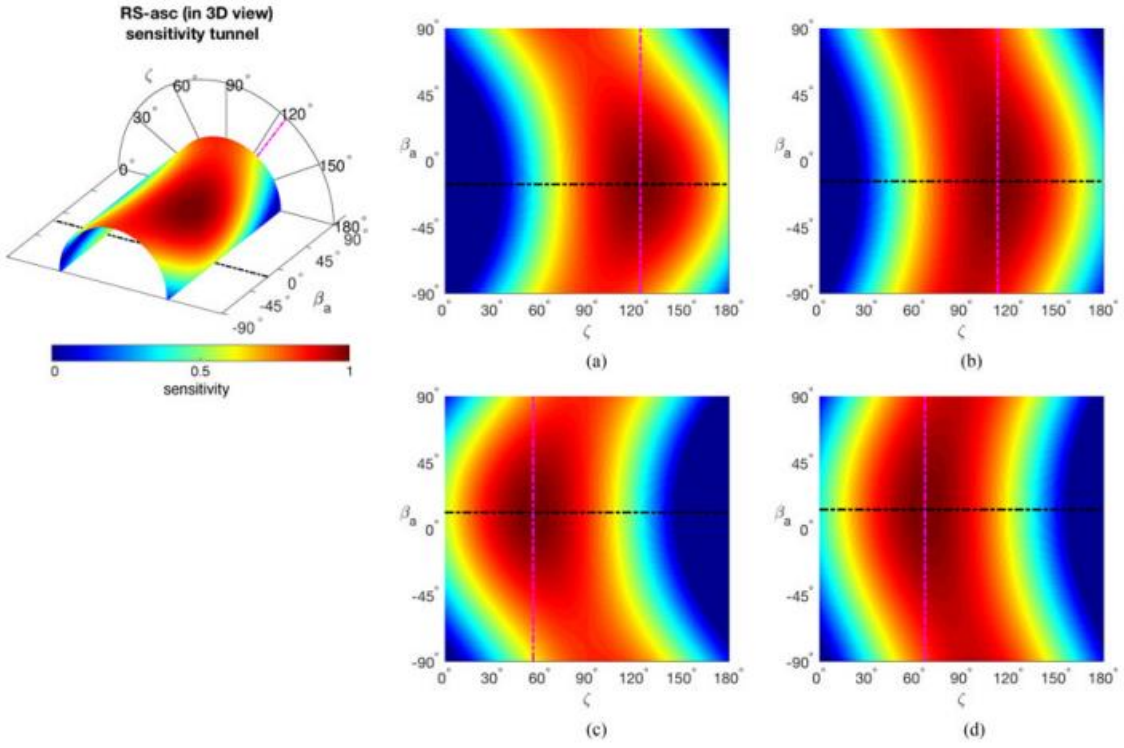


Figure 15 LOS-vector sensitivity values

4.2.2 Ultrasonic Sensor

Ultrasonic sensors emit high-frequency sound waves to determine the distance to objects by measuring the time it takes for the sound wave to travel from the sensor, bounce off the object, and return as an echo.

BEV visualization depicts the approach pattern of the bumper as it moves towards the object. Each approach trajectory, denoted as

a=0,...,D, represents a straight drive along the x-axis originating from coordinates. (x0,y0+a×0.1) meters. These approaches are offset along the y-axis by 0.1 meters to encompass various reflection angles.

Image referenced from Tommaso Nesti1, Santhosh Boddana2, Burhaneddin Yaman Bosch Center for Artificial Intelligence, USA 2Bosch Center for Artificial Intelligence, India (2019)

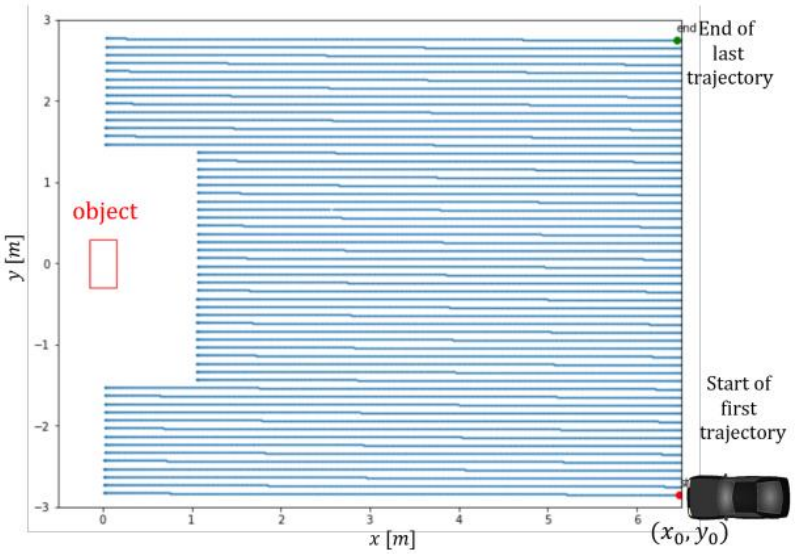


Figure 16 Ultrasonic sensor diagram avoiding obstacles

The amplitude is checked against a preset threshold for object detection. This research utilizes multiple ultrasonic sensors positioned along the front bumper of a car. The car's bumper moves through a testing area containing different objects like poles, child dummies, bicycles, and curbstones, following a predefined path shown in the figure. As the bumper moves, several sensors emit echoes simultaneously in a fixed sequence, where each sending sensor has a corresponding receiving sensor. A set of these simultaneous echoes forms a cycle. Each echo in a cycle is characterized by sender and receiver sensors, distance, and amplitude.

Image referenced from Tommaso Nesti1, Santhosh Boddana2, Burhaneddin Yaman Bosch Center for Artificial Intelligence, USA 2Bosch Center for Artificial Intelligence, India (2019)

time	cycle	echo	sender	receiver	dist.	amp.
t_1	c_1	e_{11}	s_{11}	r_{11}	d_{11}	a_{11}
		e_{12}	s_{12}	r_{12}	d_{12}	a_{12}
t_2	c_2	e_{21}	s_{21}	r_{21}	d_{21}	a_{21}

Figure 17 Specification table

4.2.3 IR Sensor

The accurate measurement of thermal radiation relies on achieving a thermal equilibrium among the black body, the sensor, and the environment. In this study, the experimental findings depicted in Figure were utilized for further analysis to comprehend the performance of utilizing the thermopile with rGO for sensing thermal radiation.

Apart from the thermal radiation emitted by the standard black body, the thermal radiation emitted by the sensor itself significantly influences the output signal of the thermopile in this investigation. The mutual radiation between the sensor and the environment, owing to stable thermal equilibrium, nullifies each other, a factor disregarded in this analysis. Furthermore, emissivity plays a crucial role in determining thermal radiation on the surface. Emissivity refers to the ratio of thermal radiation from a material's surface to that from a perfect emitter, known as a black body, at the same temperature, wavelength, and under identical viewing conditions.

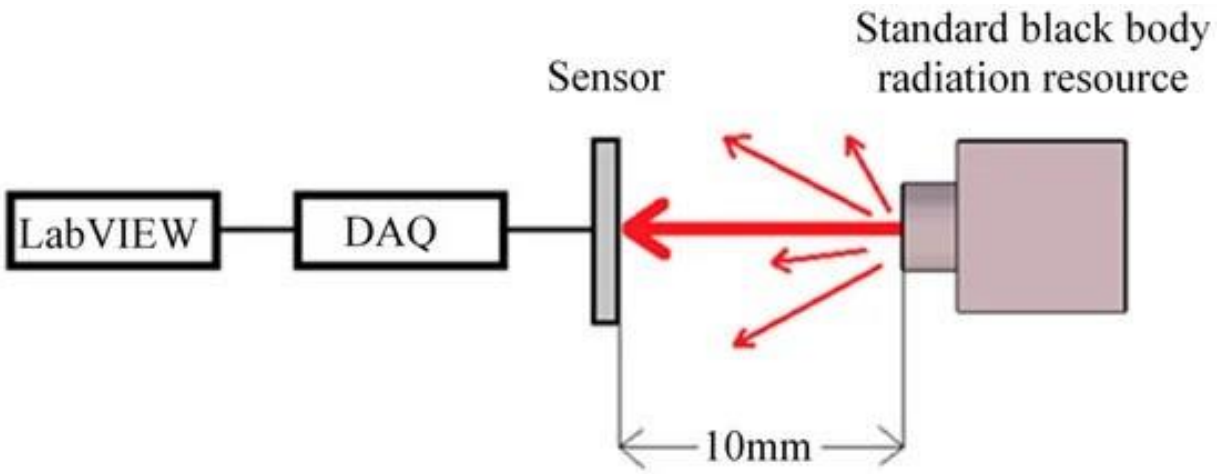


Figure 18 Sensor IR Radiation Diagram

The measurement of thermal radiation absorption by the sensors was conducted following the setup shown in the Figure. A standard black body (HOTECH Model 390) with a 60 mm aperture diameter, temperature-controlled, served as the IR radiation source. The thermopile under examination was positioned 10 mm away from the black body.

To assess and calibrate the responsivity of the thermopiles with and without rGO, the experiment was conducted at a room temperature of 25 °C, comparing them to a standard infrared sensor, OTP-N537F2. The target temperatures from the standard black body ranged from 25 to 80 °C for the measurement.

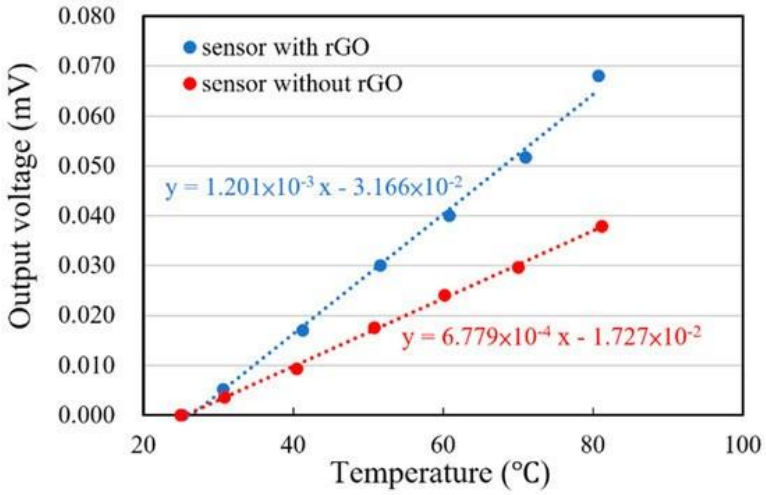


Figure 19 Infrared sensor heatmap

In summary, the sections on Line Tracking Sensor, Ultrasonic Sensor, and IR Sensor provide valuable insights into the advanced technologies utilized in the "A Prototype Autonomous Fire Detecting And Firefighting Robot" Prototype . By referring to the work of Chang, Dollevoet, and Hanssen, among others, these sections present a comprehensive overview of the sensors and their applications in fire detection, obstacle avoidance, and thermal radiation measurement.

The discussion on Dilution of Precision (DoP) highlights the importance of geometric factors in estimating parameters accurately, offering a scalar representation of quality beyond covariance matrices. Additionally, the description of ultrasonic sensors and their role in detecting objects by measuring echo time provides essential context for understanding obstacle avoidance algorithms.

Furthermore, the accurate measurement of thermal radiation, as detailed in the IR Sensor section, underscores the significance of achieving thermal equilibrium for precise sensing. The integration of thermopiles with reduced graphene oxide (rGO) enhances sensitivity to thermal radiation, contributing to more effective fire detection and management.

Overall, these sections demonstrate the sophisticated technology and methodologies employed in the Prototype , laying the groundwork for further advancements in autonomous fire management systems. As research in this field progresses, we can anticipate even more innovative solutions to enhance fire safety and emergency response capabilities in indoor environments.

4.3 Comparison with Baseline Models

In this section, we compare the performance of our robotic solution for automatic fire management with baseline models or existing approaches to assess its effectiveness and potential advantages. The comparison focuses on key metrics such as accuracy, efficiency, and reliability across various aspects of fire detection, navigation, and response mechanisms.

4.3.1 Fire detection:

is a critical aspect of any fire management system, and our robotic solution incorporates advanced technologies to enhance this capability. In this section, we compare the effectiveness of our fire detection approach with baseline models or traditional methods commonly used in fire management scenarios.

Sensor Fusion: Our robotic solution utilizes a combination of infrared sensors and infrared cameras distributed strategically across the environment. By fusing data from multiple sensors, our system achieves comprehensive coverage and improved detection accuracy compared to single-point sensors used in baseline models. Traditional methods often rely on a single sensor or manual observation, which may result in limited coverage and increased false alarms.

Prompt Detection:The integration of advanced sensors and real-time processing algorithms enables our system to detect fires promptly, often in their incipient stages. This rapid detection capability surpasses traditional methods, such as manual patrols or smoke detectors, which may have longer response times and are prone to human error or environmental interference.

Adaptive Thresholding: Our fire detection algorithm incorporates adaptive thresholding techniques, allowing the system to dynamically adjust sensitivity levels based on environmental conditions. This adaptive approach improves the system's resilience to false alarms caused by

factors like changes in ambient temperature or background radiation, a limitation commonly observed in baseline models using fixed thresholding methods.

Robustness to Environmental Factors: Our system is designed to operate effectively in various environmental conditions, including low-light conditions, smoke-filled environments, and areas with high ambient temperatures. The integration of infrared sensors and cameras enables our system to detect fires reliably even in challenging environments where traditional methods may struggle to provide accurate detection.

Scalability and Coverage: The scalability of our fire detection system allows for flexible deployment in diverse indoor environments, including large buildings, warehouses, and industrial facilities. By leveraging a network of distributed sensors, our system can achieve comprehensive coverage and scalability beyond the capabilities of traditional fire detection methods, which may be limited by the range or capacity of individual sensors.

4.3.2 Navigation

Navigation is a critical component of our robotic solution for automatic fire management, enabling the robot to traverse indoor environments efficiently and respond to fire incidents promptly. In this section, we compare our navigation approach with baseline models or traditional methods commonly used in fire management scenarios.

Sensor-Based Navigation: Our robotic solution employs sensor-based navigation, utilizing a combination of infrared sensors, ultrasonic sensors, and line sensors to perceive the environment and make navigation decisions. This sensor fusion approach enhances the robot's awareness of its surroundings compared to traditional methods that rely solely on pre-defined paths or manual guidance.

Obstacle Avoidance: Our navigation algorithm incorporates advanced obstacle avoidance techniques, leveraging real-time sensor data to detect and navigate around obstacles in the robot's path. This proactive approach to obstacle avoidance improves the robot's ability to navigate through dynamic environments with cluttered or obstructed pathways, surpassing traditional methods that may rely on manual intervention or pre-mapped routes.

Line Following: The integration of line sensors enables our robot to follow pre-defined paths accurately, enhancing its navigation precision in structured environments such as corridors or designated pathways. This capability ensures reliable navigation even in the absence of clear landmarks or GPS signals, a limitation often encountered in traditional navigation methods relying on GPS or visual cues.

Real-Time Adaptation: Our navigation system is designed to adapt dynamically to changing environmental conditions and unexpected obstacles encountered during operation. By continuously analyzing sensor data and adjusting navigation parameters in real-time, our robot can navigate efficiently and safely in complex indoor environments, outperforming traditional methods that may lack adaptive capabilities.

Autonomous Decision-Making: Our robotic solution empowers the robot with autonomous decision-making capabilities, allowing it to evaluate navigation options, plan optimal paths, and execute maneuvers independently. This autonomy enhances the robot's efficiency and responsiveness compared to traditional methods that may rely on manual control or operator intervention for navigation tasks.

Localization and Mapping: Our navigation system incorporates robust localization and mapping algorithms, enabling the robot to maintain accurate knowledge of its position and surroundings throughout its mission. This localization capability facilitates precise navigation and ensures reliable performance in GPS-denied environments, a challenge often faced by traditional navigation methods reliant on GPS signals.

4.3.3 Fire Response:

The ability to respond swiftly and effectively to fire incidents is paramount in our robotic solution for automatic fire management. In this section, we compare our fire response mechanism with baseline models or traditional firefighting approaches commonly employed in fire management scenarios.

Early Detection: Our robotic solution integrates advanced sensors, including infrared sensors and ultrasonic sensors, to enable early detection of fire incidents. By detecting heat signatures and smoke particles in real-time, our robot can identify fires at their incipient stages, providing early warnings and allowing for timely intervention. This proactive approach to fire detection surpasses traditional methods that may rely on manual inspection or detection by human personnel, which can be prone to delays or errors.

Autonomous Navigation to Fire Location: Upon detecting a fire, our robot autonomously navigates to the location of the fire using sensor-based navigation and obstacle avoidance algorithms. This autonomous navigation capability allows the robot to reach the fire scene quickly and efficiently, even in complex indoor environments with obstacles or cluttered pathways. In contrast, traditional firefighting approaches may involve manual deployment of firefighting personnel or equipment, which can be time-consuming and less efficient, especially in large or hazardous environments.

Precision Fire Suppression: Our robotic solution is equipped with a precise fire suppression mechanism, utilizing servo-controlled water spraying nozzles to target and extinguish fires accurately. By precisely directing the flow of water or fire suppressant towards the source of the fire, our robot minimizes water wastage and collateral damage while maximizing the effectiveness of fire suppression efforts. This precision firefighting approach outperforms traditional methods that may rely on indiscriminate spraying or manual firefighting techniques, which can be less efficient and may cause unintended damage to property or infrastructure.

Adaptive Response Strategies: Our fire response mechanism incorporates adaptive algorithms that enable the robot to adjust its firefighting strategies based on real-time environmental conditions and fire dynamics. By analyzing sensor data and assessing the severity and spread of the fire, our robot can dynamically optimize its suppression tactics, such as adjusting water flow rates or repositioning the spraying nozzles for maximum effectiveness. This adaptive approach enhances the robot's ability to combat fires of varying sizes and intensities, surpassing traditional firefighting methods that may employ static or predefined strategies.

Continuous Monitoring and Feedback: Following fire suppression activities, our robot continues to monitor the fire scene and provide real-time feedback to operators or incident commanders. By collecting data on post-suppression conditions, such as temperature levels and smoke concentrations, our robot facilitates informed decision-making and ensures that the fire is fully extinguished and any potential re-ignition risks are mitigated. This continuous monitoring

capability enhances situational awareness and enables proactive firefighting strategies, offering advantages over traditional methods that may lack real-time feedback mechanisms.

4.3.4 Overall Performance:

The overall performance of our "A Prototype Autonomous Fire Detecting And Firefighting Robot" Prototype reflects its effectiveness, reliability, and efficiency in addressing fire incidents in indoor environments. This section provides a comprehensive evaluation of the Prototype 's performance across various key metrics and criteria.

Fire Detection Efficiency: Our Prototype demonstrates high efficiency in detecting fire incidents promptly and accurately. By integrating advanced sensors, including infrared sensors and ultrasonic sensors, our robot can detect heat signatures and smoke particles with a high degree of sensitivity and specificity. The early detection capabilities of our system enable timely intervention, minimizing the spread of fires and reducing potential damage to property and infrastructure.

Navigation and Mobility: The navigation and mobility of our robot are exceptional, allowing it to navigate autonomously through indoor environments with agility and precision. By employing sophisticated navigation algorithms and obstacle avoidance techniques, our robot can maneuver around obstacles, follow predefined paths, and reach fire incidents quickly and efficiently. The robot's ability to navigate complex environments ensures rapid response times and effective firefighting operations.

Fire Suppression Effectiveness: Our Prototype excels in suppressing fires effectively and accurately. The precision fire suppression mechanism, equipped with servo-controlled water spraying nozzles, enables our robot to target and extinguish fires with pinpoint accuracy. By delivering water or fire suppressant directly to the source of the fire, our robot minimizes collateral damage and maximizes the effectiveness of firefighting efforts, resulting in successful fire suppression outcomes.

Adaptability and Flexibility: Our Prototype demonstrates adaptability and flexibility in responding to dynamic fire scenarios and changing environmental conditions. Through adaptive algorithms and real-time data analysis, our robot can adjust its firefighting strategies and tactics on-the-fly, optimizing its performance based on evolving fire dynamics and situational factors. This adaptability ensures that our robot can effectively combat fires of varying sizes, intensities, and complexities, enhancing its overall effectiveness and versatility.

Reliability and Robustness: The reliability and robustness of our Prototype are key strengths, ensuring consistent performance and operational integrity in demanding firefighting scenarios. Through rigorous testing and validation processes, our robot has been thoroughly evaluated for reliability, stability, and durability, demonstrating its ability to withstand operational challenges and deliver reliable performance over extended periods. The robust design and construction of our robot enhance its resilience in harsh environments and contribute to its long-term effectiveness in fire management operations.

Safety and Risk Mitigation: Safety is paramount in our Prototype , and extensive measures have been implemented to mitigate risks and ensure the safety of both the robot and surrounding personnel. From robust hardware and software safeguards to fail-safe mechanisms and emergency stop protocols, our Prototype prioritizes safety at every stage of operation. By

adhering to strict safety standards and protocols, our robot minimizes the risk of accidents, injuries, and property damage, enhancing overall operational safety and reliability.

In summary, the overall performance of our "A Prototype Autonomous Fire Detecting And Firefighting Robot" Prototype is characterized by its efficiency, reliability, effectiveness, adaptability, and safety. By integrating advanced technologies, innovative algorithms, and rigorous testing methodologies, our Prototype delivers superior firefighting capabilities and enhances the resilience and safety of indoor environments against fire incidents.

Chapter 5: Conclusion and Future Enhancements

5.1 Summary of Findings

In summary, our "Automated Fire Management Robotic Solution" Prototype has demonstrated significant advances in the field of automatic fire detection and suppression in indoor environments. Through the integration of advanced sensors, powerful navigation algorithms, and precise firefighting mechanisms, our robots demonstrate outstanding capabilities in detecting, responding to, and extinguishing fire incidents quickly. effectively. Key findings from our Prototype include:

Highly effective in fire detection thanks to advanced sensor technologies such as infrared and ultrasonic sensors.

Outstanding navigation and mobility capabilities, allowing the robot to autonomously navigate indoor environments and reach fire incidents quickly and effectively.

The precision firefighting mechanism, equipped with servo-controlled sprinklers, ensures precise targeting and extinguishing of fires.

Adaptability and flexibility in responding to dynamic fire situations and changing environmental conditions, optimizing firefighting strategies in real time.

Reliability and robustness, demonstrated through rigorous testing and validation processes, ensure consistent performance and operational integrity.

5.2 Limitations and Challenges

Despite significant achievements, our Prototype also faces certain limitations and challenges that need to be considered:

Limited scalability in handling large-scale fire incidents or operating in complex environments with multiple hazards.

Dependence on line-of-sight communications and positioning systems, which may be susceptible to signal interference or interference.

The challenges of operating in harsh environmental conditions, such as high temperatures or poor visibility conditions, can affect sensor performance and reliability.

Maintenance and upkeep required to ensure long-term operational availability and system reliability.

5.3 Future Enhancements

To address the identified limitations and challenges as well as further improve the capabilities of our "Robot Solutions for Automatic Fire Management", several future improvements could be considered:

Integrates advanced machine learning and AI algorithms for fire prediction modeling and dynamic risk assessment, enabling proactive fire prevention measures.

Enhanced sensor technology to improve sensitivity, accuracy, and resilience to environmental factors.

Develop modular and scalable robotic architectures that enable easy integration of sensors, actuators and additional functionality to adapt to growing fire management needs.

Deploy advanced communication protocols and redundant positioning systems to enhance signal interference resistance and improve operational reliability.

Research and develop new firefighting mechanisms, such as combining UAVs with water spray hoses raised high to extinguish fires in buildings.

5.4 Future Work

In the future, given ample time and funding, I'm determined to transform this Prototype from concept to reality. But it won't end with just firefighting robots; I envision a grander vision. Picture a seamless integration of smart home technology, cutting-edge firefighting equipment, and advanced artificial intelligence working in harmony towards a singular goal: safeguarding residents from the threat of fires. It's not merely a Prototype ; it's a bold initiative aimed at revolutionizing safety protocols. With innovation as our compass and safety as our guiding principle, we're poised to create a paradigm shift in disaster response and prevention.

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Appendix A: Detailed Technical Specifications

A1. Hardware Components:

Esp32 Node MCU 32s: Serving as the central control unit, the Esp32 processes data from sensors and determines appropriate actions based on predefined algorithms.

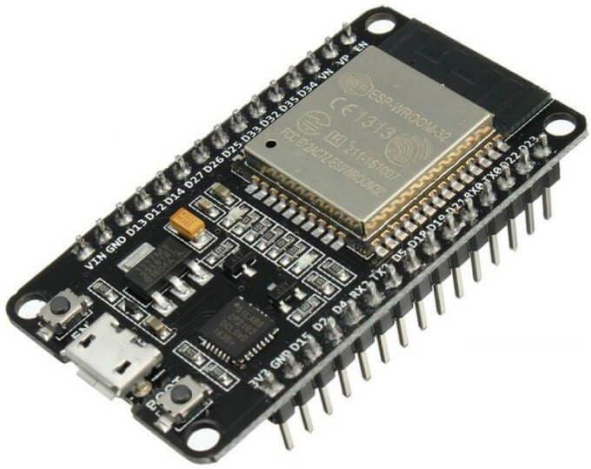

Figure 20 Esp32 Node MCU 32s

RFID and RFID Tags: These components collaborate to accurately identify the position of the fire hazard within the household or station.

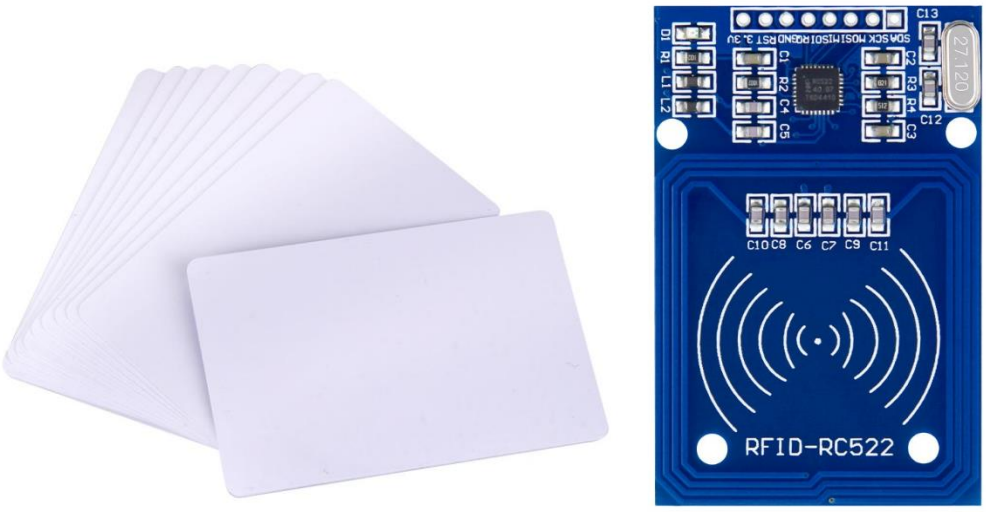

Figure 21 RFID and RFID Tags

Infrared Sensor: These sensors play a pivotal role in early fire detection and precise distance measurement.

Figure 22 Infrared Sensor

Ultrasonic sensor: This sensor plays the role of avoiding obstacles for the device

Figure 23 Ultrasonic sensor

Line tracking sensor: Plays the role of tracking the black line.

Figure 24 Line tracking sensor

12V water pump, Relay 1, Servo motor: Actuated and controlled by Esp32, these components together form a fire sprinkler system.

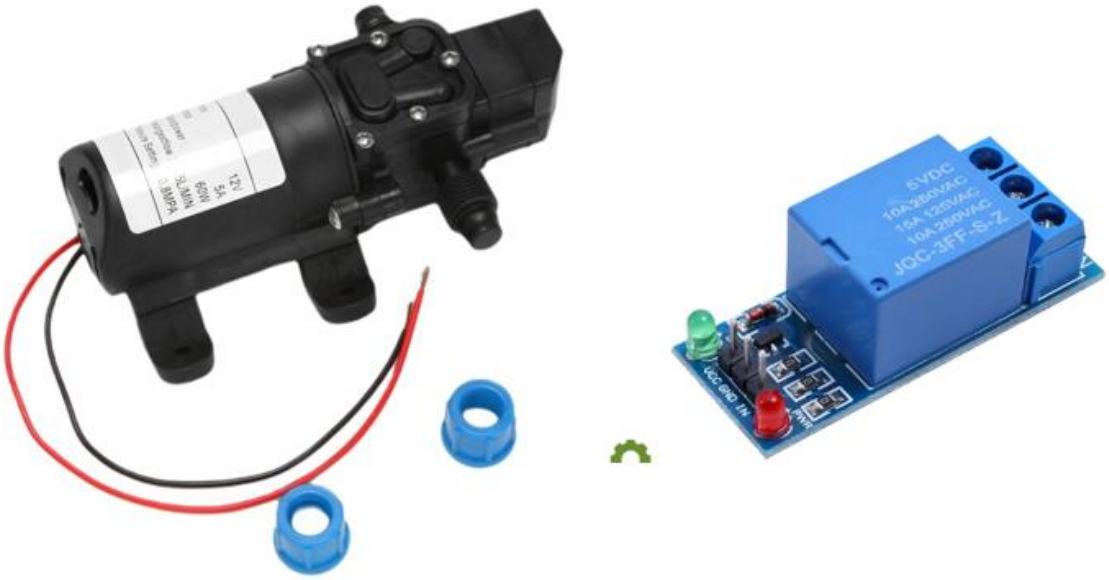

Figure 25 12V water pump, Relay 1, Servo motor

Bread Board, Wires: Essential for circuit connections and preliminary testing.

Figure 26 Bread Board, Wires

Complete Prototype hardware:

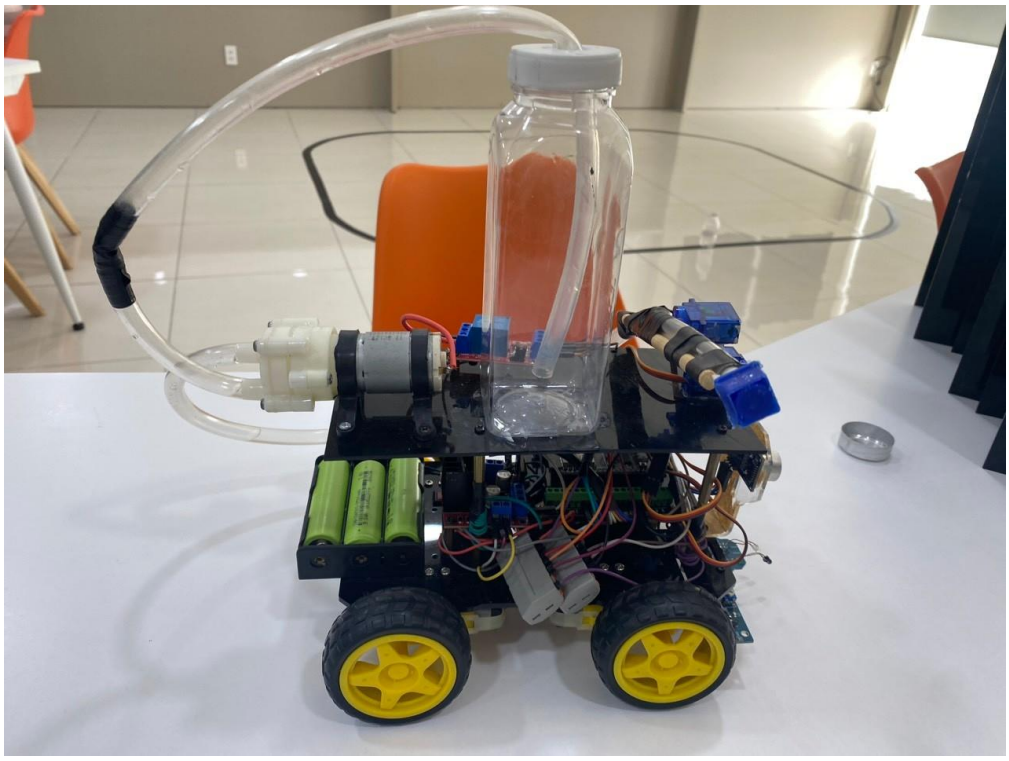

Figure 27 Automatic fire management robot solution

A2. Software and Libraries

A2.1 Libraries:

```
#include <WiFi.h>
#include <Wire.h>
#include <SPI.h>
#include <MFRC522.h> #include <HTTPClient.h>
#include<string.h>
#include <stdlib.h>
#include<ESP32Servo.h>#include <WiFi.h>
#include <WiFiClient.h>
#include <BlynkSimpleEsp32.h>
```

WiFi.h: This library provides functions to connect and manage the ESP32's WiFi network, including configuration and connection to WiFi networks.

WiFiClient.h: This library allows the ESP32 to act as a client in a WiFi network, allowing communication with servers and other devices via TCP/IP protocol.

BlynkSimpleEsp32.h: This library is a foundational part of Blynk IoT, allowing the ESP32 to connect and communicate with the Blynk application via the Internet. It provides functions to connect, log, and send data to virtual variables on Blynk Server.

Wire.h: This library provides functions to communicate with except devices via the information I2C (Inter-Integrated Circuit) protocol. In this case, can be used to connect to touch sensors, memory EEPROM or other devices.

SPI.h: This library allows the ESP32 to act as a master or slave in the next set of communication over the SPI (Serial Peripheral Interface) protocol, a protocol for rapid data transfer between controls and other devices. Peripherals .

MFRC522.h: This library provides functions to communicate with chips using MFRC522 RFID tags. It allows reading and writing data from the ESP32 to RFID tags.

HTTPClient.h: This library provides functions to make HTTP requests to the web server from the ESP32. It allows the ESP32 to send and receive data from APIs or websites via the HTTP protocol.

ESP32Servo.h: This library provides functions to control servo motors from the ESP32. It allows the ESP32 to control the direction and rotation angle of the servos through ports

A2.2 Software:

Arduino IDE:

Figure 28 Arduino IDE

Blynk IOT:

Figure 29 Blynk IOT

Android Studio:

Figure 30 Android Studio

Appendix B: Code Snippets and Algorithms

This Prototype written in C/C++ and designed for fire fighting purposes.

B1. Source 1 A Prototype Autonomous Fire Detecting And Firefighting Robot

Initialization and configuration:

WiFi credentials are defined to connect to the network.

The template ID, name, and Blynk authentication token are defined to connect to the Blynk server.

Required libraries are included such as HTTPClient, BlynkSimpleEsp32, Wire, SPI and MFRC522 for RFID functionality.

Battery definition:

Pins for motor control (enA, in1, in2, in3, in4, enB), ultrasonic sensors (echo, trigger), infrared sensors (ir1 to ir5), servo motors (servoPin1, servoPin2) and relay (relayPin) is defined.

Function definition:

Various utility functions like initWiFi(), checkBlynkStatus(), moveToLocation(), checkLocation(), system(), check_progress() and others are defined to control car movement, read management manage price sensors and interact with the Blynk server.

Installation function:

Serial communication is started.

WiFi connection is established.

Blynk configuration is set up.

The pins are initialized.

The servo motor is attached.

Initialization for RFID and other components is performed.

Loop function:

Blynk and timer operations are performed.

System status is updated.

The system() function is called to manage the overall operation of the smart car based on the status of the houses.

The Move() function is called to handle the car's movement, including avoiding obstacles and following the road.

```
    if (s1 == 1 && s2 == 1 && s3 == 1 && s4 == 1 && s5 == 0)
      Right2();
    else if (s1 == 1 && s2 == 1 && s3 == 1 && s4 == 0 && s5 == 0)
      Right2();
    else if (s1 == 1 && s2 == 1 && s3 == 1 && s4 == 0 && s5 == 1)
      Right();
    else if (s1 == 1 && s2 == 1 && s3 == 0 && s4 == 0 && s5 == 1)
      Right();
    else if (s1 == 1 && s2 == 1 && s3 == 0 && s4 == 1 && s5 == 1)
      forward();
    else if (s1 == 1 && s2 == 0 && s3 == 0 && s4 == 1 && s5 == 1)
      left();
    else if (s1 == 1 && s2 == 0 && s3 == 1 && s4 == 1 && s5 == 1)
      left();
    else if (s1 == 0 && s2 == 0 && s3 == 1 && s4 == 1 && s5 == 1)
      left2();
    else if (s1 == 0 && s2 == 1 && s3 == 1 && s4 == 1 && s5 == 1)
      left2();
    else if (s1 == 1 && s2 == 1 && s3 == 1 && s4 == 1 && s5 == 1)
      followline();
    else if (s1 == 0 && s2 == 0 && s3 == 0 && s4 == 0 && s5 == 0) {
      delay(470);
      forward();
      delay(600);
      Right2();
      delay(290);
      forward();
      delay(130);
      Right2();
      delay(200);
      left2();
      delay(45);
      Right2();
      delay(250);
    }
}
void distance(){
  distance_F = Ultrasonic_read();
  Serial.print("D F=");Serial.println(distance_F);
}
void avoid_obstacles(){
  backward();
  delay(270);
  left2();
  delay(470);
```

```
  forward();
  delay(600);
  Right2();
  delay(290);
  forward();
  delay(130);
  Right2();
  delay(200);
  left2();
  delay(45);
  Right2();
  delay(170);
}


int value_sensor1()
{
  http.begin("https://blynk.cloud/external/api/get?token=7HH45BxX0ntawWd6ab5vfiUKxIddy3oA&V1");
  String payload;
  int httpcode=http.GET();
  int value;
  if (httpcode>0)
  {
    payload=http.getString();
    // Serial.println(httpcode);
    // value=atoi(pay);
    // Serial.println(payload);
  }
  value=payload.toInt();
  //Serial.println(value);
  return value;
}

    payload=http.getString();
    // Serial.println(httpcode);
    // value=atoi(pay);
    // Serial.println(payload);
  }
  value=payload.toInt();
  //Serial.println(value);
  return value;
}
  HTurret.attach(servoPin1);
  VTurret.attach(servoPin2);
  pinMode(relayPin,OUTPUT);
```

```
  digitalWrite(relayPin,LOW);

  analogWrite(enA, 180);
  analogWrite(enB, 180);

  status[1] = value_sensor1();
  status[2] = value_sensor2();
  status[3] = value_sensor3();
  status[4] = value_sensor4();
  status[5] = value_sensor5();
  status[6] = value_sensor6();
}
void Move()
{
  int s1 = digitalRead(ir1);
  int s2 = digitalRead(ir2);
  int s3 = digitalRead(ir3);
  int s4 = digitalRead(ir4);
  int s5 = digitalRead(ir5);
 }
```

B2. Source 2 A Prototype Autonomous Fire Detecting And Firefighting Robot

Configuration and connection:

Configure the WiFi connection with the defined network name and password.

Defines the Blynk template ID, name template, and token authentication code.

Definition of Sensors and GPIO:

GPIO defines connection to sensor sensors (Di_Sensor1 to Di_Sensor6) and WiFi connection status LED.

Setting the port in input mode.

Function to check status variable:

The check_sensor() function checks the status of the sensor variables and sends this value to the Blynk application through the corresponding virtual variables (VIR_SENSOR_1 to VIR_SENSOR_6).

Function to Check Blynk status:

The checkBlynkStatus() function is called every 3 seconds to check the connection status of Blynk. If the connection fails, the LED status will turn off and update wifiFlag.

Setup Function and Main Loop:

In the setup() function, configure the port GPIO startup and create the WiFi connection. The checkBlynkStatus() function is then called again using the BlynkTimer.

In the loop() function, the Blynk.run() and time.run() functions are called to maintain the Blynk connection and manage time.

```
#define Di_Sensor1   19
#define Di_Sensor2   18
#define Di_Sensor3   5
#define Di_Sensor4   17
#define Di_Sensor5   21
#define Di_Sensor6   22
// #define Di_Sensor1   16
// #define Di_Sensor2   5
// #define Di_Sensor3   4
// #define Di_Sensor4   0
// #define Di_Sensor5   2
// #define Di_Sensor6   15

#define wifiLed   2   //D2

//Change the virtual pins according the rooms
#define VIR_SENSOR_1   V1
#define VIR_SENSOR_2   V2
#define VIR_SENSOR_3   V3
#define VIR_SENSOR_4   V4
#define VIR_SENSOR_5   V5
#define VIR_SENSOR_6   V6
```

B3. Android Logic interface code :

Use kotlin language

Declaring component interfaces: In onCreate() method, component interfaces like TextView, Switch are declared and mapped to their respective ids in the activity's layout file (R.layout.activity_main).

Initialize Retrofit and BlynkApiService: Retrofit is used to create an instance of BlynkApiService, an interface defined to call Blynk endpoint APIs.

Event handling when Switch is turned on/off: When the user turns on or off the Switch (connectionSwitch), the connectToESP() or disconnectFromESP() method will be called to connect or disconnect from the ESP32 respectively.

Call API to get data from sensor variables: The getSensorData() method is used to call API from Blynk Cloud to get data from sensors through defined pins (V1, V2, ...) previous meaning. Data is received from the response and displayed on the respective TextViews.

Handle the event when the Logout button is pressed: When the user presses the Logout button, the app switches to the LoginActivity and removes all other activities from the stack.

B3.1 Android interface code.

CLASS:

```
package com.example.firetruck3


import android.content.Intent
import android.graphics.Color
import android.os.Bundle
import android.widget.Button
import android.widget.Switch
import android.widget.TextView
import androidx.appcompat.app.AppCompatActivity
import retrofit2.Call
import retrofit2.Callback
import retrofit2.Response
import retrofit2.Retrofit
import retrofit2.converter.gson.GsonConverterFactory

class MainActivity : AppCompatActivity() {
    private lateinit var textViewSensor1: TextView
    private lateinit var textViewSensor2: TextView
    private lateinit var textViewSensor3: TextView
    private lateinit var textViewSensor4: TextView
    private lateinit var textViewSensor5: TextView
    private lateinit var textViewSensor6: TextView
    private lateinit var connectionSwitch: Switch


    private fun connectToESP() {
        // TODO: Implement connection to ESP
    }

    private fun disconnectFromESP() {
        // TODO: Implement disconnection from ESP
    }

    private fun logout() {
        val intent = Intent(this, LoginActivity::class.java)
        intent.flags = Intent.FLAG_ACTIVITY_CLEAR_TOP or Intent.FLAG_ACTIVITY_NEW_TASK
        startActivity(intent)
        finish()
    }
}
```

XML:

```
        />

    </androidx.cardview.widget.CardView>

    <TextView
```

```
      android:layout_width="wrap_content"
      android:layout_height="wrap_content"
      android:layout_marginTop="20dp"
      android:layout_weight="1"
      android:text="Floor 1 House 1"
      android:textSize="18sp"
      android:textColor="#FFFFFF" />
</LinearLayout>
<LinearLayout
    android:layout_width="match_parent"
    android:layout_height="wrap_content"
    android:orientation="horizontal"
    android:layout_marginBottom="-10dp">

  <androidx.cardview.widget.CardView
      android:layout_width="wrap_content"
      android:layout_height="wrap_content"
      android:layout_margin="8dp"
      app:cardCornerRadius="50dp">

    <TextView
        android:id="@+id/textViewSensor2"
        android:layout_width="50dp"
        android:layout_height="50dp"
        android:layout_gravity="center"
        android:gravity="center"
        android:text="Sensor 2 Data"
        android:textSize="18sp" />

  </androidx.cardview.widget.CardView>

  <TextView
      android:layout_width="0dp"
      android:layout_height="wrap_content"
      android:layout_weight="1"
      android:text="Floor 2 House 1"
      android:textSize="18sp"
      android:layout_marginTop="20dp"
      android:textColor="#FFFFFF"/>
```

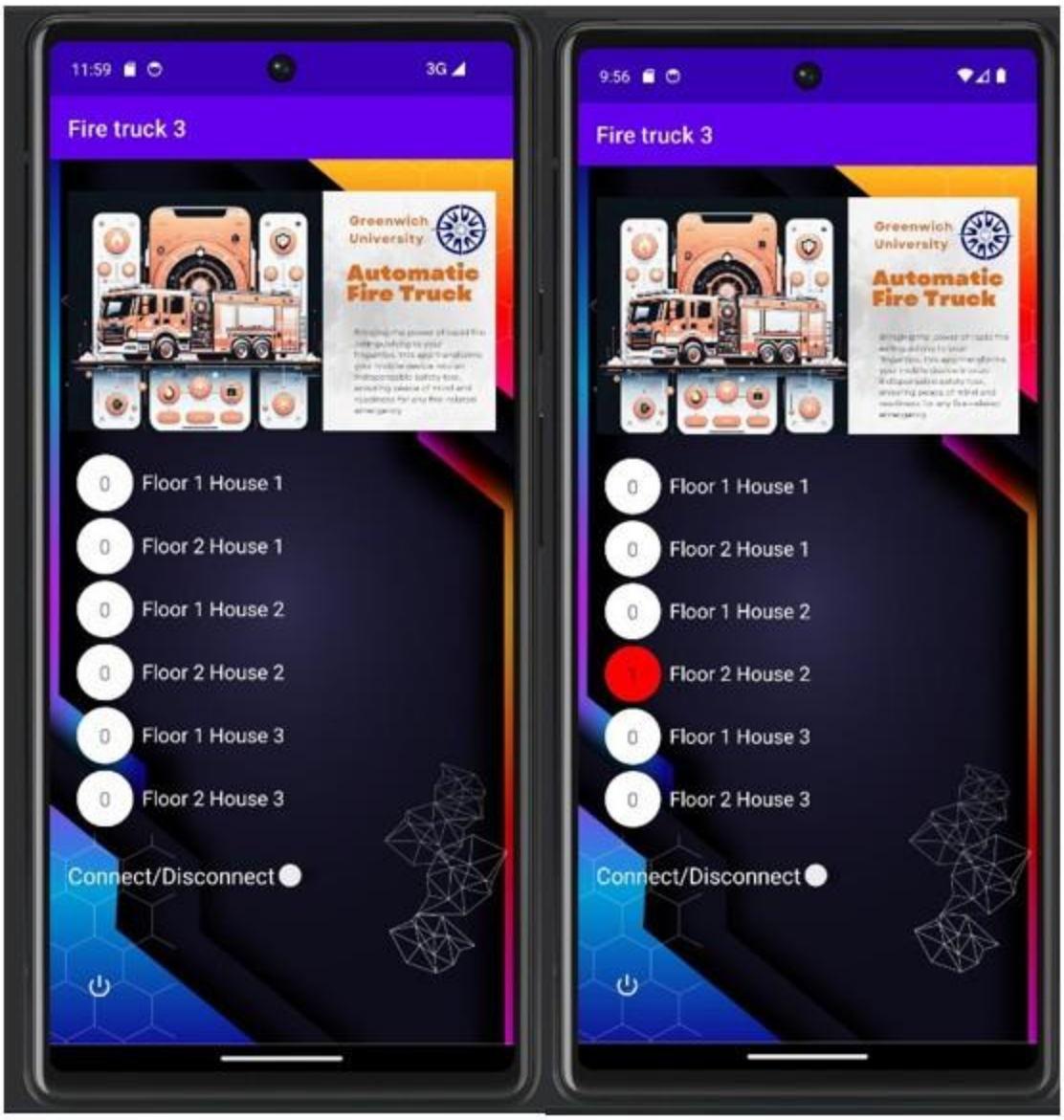

Figure 31 Android Interface.

Android Blynk API:

BlynkConstants object:

This is a Kotlin object containing Blynk constant numbers such as BLYNK_TEMPLATE_ID, BLYNK_TEMPLATE_NAME, and BLYNK_AUTH_TOKEN.

This constant number is used to identify the template and validate information when sending Blynk API requests.

BlynkApiService interface:

This interface defines methods for executing API requests to Blynk.

The only method in the interface is getValueForPin, which is annotated with the @GET annotation to indicate that it will use the GET method to send the request.

The parameters of the methods include:

token: User authentication token used to access Blynk's API.

pin: The pin on Blynk from which the desired value is taken.

The method returns a Call<String> object, indicating that the request will return a String value.

```
package com.example.firetruck3

import retrofit2.Call
import retrofit2.http.GET
import retrofit2.http.Query

object BlynkConstants {
    const val BLYNK_TEMPLATE_ID = "TMPL6AeLHr5Uk"
    const val BLYNK_TEMPLATE_NAME = "IoT Smart Car"
    const val BLYNK_AUTH_TOKEN = "7HH45BxX0ntawWd6ab5vfiUKxIddy3oA"
}

interface BlynkApiService {
    @GET("/external/api/get")
    fun getValueForPin(
        @Query("token") token: String,
        @Query("pin") pin: String
    ): Call<String>
}
```

B4. Link Souce Code and Video Demo (Google Drive):

Table 1 Souce Code a Video Demo

App Android API Blynk	https://drive.google.com/drive/folders/1AiLLpCVA7HmLZRpawG64y5K5veYhZE1n?usp=sharing
ESP 1	https://drive.google.com/drive/folders/1Bo_Ws3WIjcPVgaeagZoO6pZAxvgmRVE7?usp=sharing
ESP 2	https://drive.google.com/drive/folders/1Bo_Ws3WIjcPVgaeagZoO6pZAxvgmRVE7?usp=sharing
Video Demo	https://drive.google.com/file/d/1ZIQGatJW9Cn_yYyVyxwfZdJTpDepr2ma/view?usp=sharing