Design and Development of a Multifunctional Fire Fighting Robot Car With Live Streaming

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DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
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APPROVAL

The Project titled "**Design and Development of a Multifunctional Fire Fighting Robot Car With Live Streaming**" submitted by Mahinur Yasmin Mim (CSE2201025117), Kaniz Fatema (CSE2201025140), Sumaia Islam Dola (CSE2201025141) and Mukta Akter Sadia (CSE2201025142) to the Department of Computer Science and Engineering, Sonargaon University (SU), has been accepted as satisfactory for the partial fulfillment of the requirements for the degree of Bachelor of Science in Computer Science and Engineering and approved as to its style and contents.

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DECLARATION

We, hereby, declare that the work presented in this report is the outcome of the investigation performed by us under the supervision of **Tasnia Haque Kheya, Lecturer,** Department of Computer Science and Engineering, Sonargaon University, Dhaka, Bangladesh. We reaffirm that no part of this Project has been or is being submitted elsewhere for the award of any degree or diploma.

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ABSTRACT

This project presents the design and implementation of a multifunctional **Fire-Fighting Robot Car** with live video streaming, aimed at assisting in fire detection and preliminary fire suppression in hazardous or inaccessible environments. The proposed system is built on a four-wheel robotic platform that provides stable movement and maneuverability over uneven surfaces. An **ESP32CAM-CAM** module is integrated to enable real-time live video streaming, allowing remote monitoring through a mobile application using an access point (AP) based communication system. This feature enhances situational awareness and enables the operator to visually assess fire conditions from a safe distance. The robot is equipped with a fire detection mechanism that triggers an automated response when fire is detected. Upon detection, a built-in speaker system generates an audible alert by playing a warning sound or message, such as "fire detected," to notify nearby individuals. Additionally, a high-intensity flashlight is included, which can be remotely controlled to improve visibility in low-light or smoke-filled environments. For fire suppression, a pump motor is integrated to spray water or fire-retardant liquid toward the detected fire source, reducing the risk of fire spread during early stages. The system is powered by a rechargeable battery, ensuring portability and uninterrupted operation, and includes an onboard charging circuit for convenient and safe recharging. The combination of live streaming, audio alerting, remote monitoring, lighting control, and active fire-fighting capability makes the robot a compact and effective solution for emergency response support. Thus multifunctional robotic systems demonstrate a low-cost, scalable, and practical approach to enhancing fire safety and reducing human exposure to dangerous fire environments.

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LIST OF ABBREVIATIONS

AP	Access Point
CS	Chip Select
DOS	Disk Operating System
LED	Light Emitting Diode
MCAD	Mechanical Computer-Aided Design
MCU	Microcontroller Unit
MISO	Master In Slave Out
MOSI	Master Out Slave In
MPU	Microprocessor Unit
NXP	NXP Semiconductors
SCK	Serial Clock
SPI	Serial Peripheral Interface
TTL	Transistor–Transistor Logic
TWI	Two-Wire Interface
VCC	Voltage at the Common Collector
VR	Virtual Reality

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Fire accidents pose a serious threat to human life, property, and the environment, particularly in industrial zones, residential buildings, warehouses, and confined or hazardous areas where human intervention becomes risky. Traditional fire-fighting methods often require firefighters to operate in dangerous conditions involving high temperatures, smoke, toxic gases, and poor visibility, which can lead to severe injuries or loss of life. With the advancement of robotics, embedded systems, and wireless communication technologies, robotic fire-fighting systems have emerged as a promising solution to minimize human exposure to such hazardous environments. This project focuses on the development of a multifunctional fire-fighting robot car with live video streaming, designed to assist in early fire detection, real-time monitoring, and preliminary fire suppression. The robot is built on a four-wheel mobile platform to ensure smooth movement and stability, allowing it to navigate through affected areas effectively. An ESP32CAM-CAM module is integrated to provide real-time video streaming through a mobile access point (AP) based application, enabling remote visual monitoring and control [1],[2]. To enhance safety and awareness, the system includes a built-in speaker that automatically plays an alert message when fire is detected, warning nearby individuals. A controllable flashlight is also incorporated to improve visibility in low-light or smoke-filled environments. For active fire control, a pump motor is used to spray water or extinguishing agents toward the fire source. The robot is powered by a rechargeable battery system with an integrated charging circuit, ensuring portability and ease of maintenance. Overall, this project demonstrates a low-cost, compact, and efficient robotic solution that combines monitoring, alerting, and fire-fighting functions, making it suitable for small-scale emergency response and educational research applications.[1],[3]

1.2 Objectives:

- To design and develop a four-wheel based mobile robot capable of operating in fire-prone environments.
- To implement a fire detection system that can identify the presence of fire accurately and reliably.
- To integrate an ESP32CAM-CAM module for real-time live video streaming and remote monitoring using a mobile application.
- To develop an automated audio alert system using a built-in speaker to announce “fire detected” upon detection.
- To incorporate a remotely controllable flashlight for improved visibility in dark or smoky conditions.
- To design a pump motor–based fire suppression mechanism for initial fire control.
- To implement wireless control and monitoring using an access point (AP) based communication system.
- To design a rechargeable battery power system with an onboard charging circuit for continuous operation.
- To develop a low-cost, scalable, and user-friendly robotic system suitable for educational and practical applications.

CHAPTER 2

LITERATURE REVIEW

2.1 Existing Systems

Existing fire-fighting systems mainly rely on conventional fire detection and suppression mechanisms that offer limited mobility and situational awareness. Traditional systems such as smoke detectors, heat sensors, fire alarms, and automatic sprinkler systems are widely used in residential, commercial, and industrial buildings. These systems are effective for early fire detection and alert generation; however, they are stationary in nature and cannot actively move toward the fire source or adapt to changing fire locations. Once triggered, they mainly depend on human intervention for further action, which exposes firefighters to hazardous conditions such as extreme heat, toxic smoke, and unstable structures. In recent years, some semi-automated and robotic fire-fighting systems have been developed to address these challenges[4],[5]. Certain wheeled or tracked fire-fighting robots are capable of spraying water or fire-retardant chemicals, but many of these systems are expensive, bulky, and designed for large-scale industrial applications, making them unsuitable for small or medium environments. Additionally, several existing robotic platforms rely on wired control systems or short-range communication methods, which restrict operational range and flexibility. Some robots lack real-time video feedback, forcing operators to rely on limited sensor data rather than visual confirmation of fire conditions. Although aerial firefighting drones provide rapid deployment and overhead views, they suffer from limitations such as short battery life, low payload capacity for extinguishing agents, and instability in smoky or high-temperature environments. Furthermore, most existing systems do not integrate audio alert mechanisms to warn nearby individuals when fire is detected, reducing their effectiveness in evacuation scenarios. Power supply limitations are another drawback, as many systems depend on external power sources or non-integrated battery solutions without proper charging systems. Due to these limitations, current fire-fighting systems fail to provide a compact, low-cost, and multifunctional solution that combines mobility, live video streaming, alerting, illumination, fire suppression, and autonomous power management in a single platform[3],[6].

2.2 Our Contributions

Extensive research has been conducted in the field of fire detection and firefighting systems to improve response time, safety, and efficiency during emergency situations. Early studies primarily focused on conventional fire detection techniques using smoke sensors, temperature sensors, and flame sensors. These systems were designed mainly for stationary installations such as buildings and industrial facilities, where they provide early warnings through alarms or sprinkler activation[7],[8].

While effective in detection, researchers identified limitations such as false triggering, lack of adaptability to dynamic fire locations, and complete dependence on human intervention for suppression. To overcome these drawbacks, subsequent studies emphasized the integration of embedded systems with mobile robotic platforms, enabling automated or remote-controlled firefighting operations. The introduction of microcontroller-based systems marked a significant shift toward intelligent fire response solutions, allowing real-time processing of sensor data and automated control of actuators. Initially, platforms such as Arduino and Raspberry Pi were widely adopted due to their ease of programming and availability of development resources.

Build a mobile fire-fighting robot

- Use fire sensors to detect fire
- Use ESP32-CAM for live video streaming
- Control the robot wirelessly in AP mode
- Move the robot using four-wheel motors
- Spray water using a pump to control fire
- Use LED light for visibility
- Use speaker for fire alert
- Power the system with rechargeable batter

However, recent literature highlights a transition toward more advanced microcontrollers such as the ESP32CAM, which offers integrated Wi-Fi, Bluetooth, low power consumption, and sufficient processing capability for real-time applications. The ESP32CAM-CAM module has been widely discussed in recent research as a cost-effective solution for real-time video streaming in robotic surveillance and monitoring systems. Studies indicate that live video feedback significantly improves situational awareness by allowing operators to visually assess fire intensity, obstacles, and environmental conditions from a safe distance. Several researchers have explored different communication modes for video transmission, including cloud-based streaming and local access point (AP) based control. AP-based systems are particularly emphasized in literature for emergency scenarios where internet connectivity may be unavailable or unreliable. Mobility and navigation form another major focus area in firefighting robot research. Various locomotion mechanisms, including tracked systems, legged robots, and wheeled platforms, have been analyzed for performance in hazardous environments.

While tracked robots provide better traction on rough terrain, literature suggests that four-wheel drive robotic platforms offer an optimal balance between stability, maneuverability, mechanical simplicity, and energy efficiency, especially for indoor and semi-outdoor environments. Fire suppression mechanisms have also been extensively reviewed in existing studies. Many researchers have implemented pump motor–based water spraying systems controlled through microcontrollers for initial fire suppression.

In addition to visual aids, audio alert systems have been explored as an effective method for improving safety and evacuation awareness. Studies show that speaker-based voice alerts are more informative and effective than simple buzzers, as they can convey clear warning messages such as “fire detected” to nearby individuals. Power supply and energy management have been identified as critical challenges in mobile robotic systems. Researchers commonly recommend rechargeable battery systems, particularly lithium-ion and lithium-polymer batteries, due to their high energy density and lightweight characteristics. Literature also emphasizes the need for integrated charging circuits, battery protection, and power optimization techniques to ensure reliable and continuous operation.

More recent studies explore system-level integration, highlighting the challenges of combining sensing, communication, actuation, and power management into a compact and reliable platform. Researchers increasingly advocate for modular and scalable system designs to allow future upgrades such as autonomous navigation, artificial intelligence–based fire detection, and path planning. Overall, the reviewed literature demonstrates a clear trend toward multifunctional firefighting robots that integrate live video streaming, mobility, alerting, lighting, fire suppression, and efficient power management into a single low-cost system. These findings strongly support the relevance and necessity of the proposed multifunctional fire-fighting robot car with live streaming[5],[7],[9].

CHAPTER 3

METHODOLOGY

3.1 Description

The methodology of the proposed multifunctional fire-fighting robot car focuses on the systematic integration of sensing, control, communication, and actuation subsystems to achieve reliable fire detection, monitoring, and suppression. Initially, the system is designed around the ESP32CAM microcontroller platform due to its built-in Wi-Fi capability and compatibility with the ESP32CAM-CAM module [10],[11]. Fire detection is achieved using appropriate flame or heat sensors, which continuously monitor the surrounding environment. When the sensor detects fire, the signal is processed by the ESP32CAM, triggering predefined actions such as activating the alert system and enabling live monitoring. The ESP32CAM-CAM module establishes a wireless access point (AP) and streams real-time video to a mobile application, allowing the operator to visually assess the fire situation remotely. Based on the live video feed, the operator can manually control the robot's movement, flashlight, and pump motor through the mobile interface. The robot chassis is built using a four-wheel drive mechanism powered by DC motors, providing stable movement and maneuverability across different surfaces. A motor driver module is used to control the direction and speed of the wheels. For fire suppression, a pump motor connected to a water container is activated to spray water toward the fire source. A high-intensity flashlight improves visibility in dark or smoke-filled conditions, enhancing camera performance.

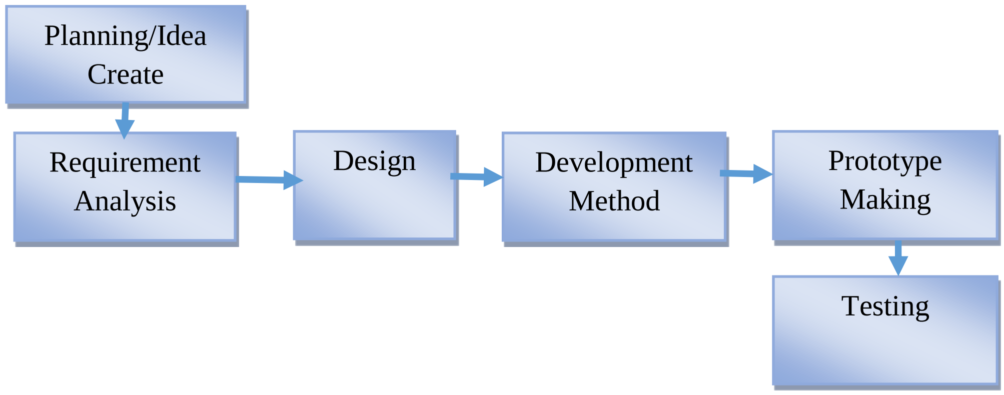


Figure 3.1: System Planning Diagram

3.2 Planning

The planning phase of the multifunctional fire-fighting robot car project focuses on defining system requirements, designing the architecture, and organizing implementation steps to ensure successful development. Initially, the problem of human risk in conventional firefighting operations is analyzed, and the need for a mobile, remotely operated firefighting solution is established. Based on this analysis, functional requirements such as fire detection, live video streaming, remote control, alert generation, lighting, and fire suppression are identified. The system architecture is then planned to integrate the ESP32CAM-CAM module, fire detection sensors, motor control unit, pump motor, speaker system, and power supply into a compact robotic platform. Component selection is carried out by considering availability, cost, power consumption, and compatibility. Mechanical planning includes designing a four-wheel chassis that can support all components while maintaining balance and mobility. Electrical planning focuses on power distribution, voltage regulation, and safe charging of the rechargeable battery. Software planning involves developing firmware for sensor data processing, motor control, wireless communication, and real-time video streaming. The mobile application interface is planned to allow intuitive control of robot movement, flashlight operation, and pump activation while displaying live video feedback [12],[13]. Finally, testing and evaluation strategies are planned to verify individual module functionality and overall system performance. This structured planning approach ensures efficient implementation, reduces development errors, and results in a reliable and multifunctional fire-fighting robotic system.

3.3 Requirement Analysis

Table 3.3.1: List of the Components with Price

Sl. No.	Component Name	Specification / Description	Quantity	Approx. Price (BDT)
1	ESP32CAM Development Board	ESP32CAM Wi-Fi + Bluetooth MCU	1	600 – 900
2	ESP32CAM-CAM Module	OV2640 camera, Wi-Fi video streaming	1	700 – 1,000
3	FTDI / USB-TTL Converter	For ESP32CAM-CAM programming	1	250 – 400
4	Flame Sensor Module	IR based fire detection	1	150 – 250
5	Motor Driver Module	L298N / L293D dual H-bridge	1	250 – 400
6	DC Gear Motors	12V / 6V, high torque	4	150 – 250 (each)
7	Robot Chassis	4-wheel robot car frame	1	800 – 1,200
8	Water Pump Motor	DC mini submersible pump	1	200 – 350
9	Water Pipe & Nozzle	Flexible pipe for spraying	1 set	100 – 200
10	High Power LED / Flashlight	For low-light visibility	1	100 – 200
11	Speaker / Mini Sound Module	Voice alert (“Fire detected”)	1	150 – 300
12	Audio Module (optional)	ISD1820 / DFPlayer Mini	1	250 – 450
13	Rechargeable Battery	18650 Li-ion (3.7V)	2–3	200 – 300 (each)
14	Battery Holder	18650 holder	1	80 – 150
15	Charging Module	TP4056 with protection	1	80 – 120
16	Buck Converter	LM2596 voltage regulator	1	150 – 250
17	Power Switch	On/Off toggle switch	1	30 – 50
18	Jumper Wires	Male–Male, Male–Female		100 – 150

3.4 Hardware Requirements

Among the many raw materials, we have used to make this pack are ESP32CAM, a series of circuit boards with a series of ESP32CAM microcontrollers. We have used some more electronics components which we are highlighting below step by

1. ESP32CAMcam
2. SD Card Module
3. Speaker
4. Relay Module
5. Wheel
6. Gear Motor
7. L298 motor driver
8. Battery
9. Pump
10. PVB, etc.

1: ESP32CAM

Figure 3.4.1: ESP32Cam

ESP32CAM is the world's leading open-source hardware and software ecosystem. The Company offers a range of software tools, hardware platforms and documentation enabling almost anybody to be creative with technology.
ESP32CAM is a popular tool for IoT product development as well as one of the most successful tools for STEM/STEAM education. Hundreds of thousands of designers, engineers, students, developers and makers around the world are using ESP32CAM to innovate in music, games, toys, smart homes, farming, autonomous vehicles, and more.

Originally started as a research project by Massimo Banzi, David Cuartielles, Tom Igoe, Gianluca Martino, and David Mallis at the Interaction Design Institute of Ivrea in the early 2000s, it builds upon the Processing project, a language for learning how to code within the context of the visual arts developed by Casey Reas and Ben Fry as well as a thesis project by Hernando Barragan about the Wiring board.
The first ESP32CAM board was introduced in 2005 to help design students — who had no previous experience in electronics or microcontroller programming — to create working prototypes connecting the physical world to the digital world. Since then it has become the most popular electronics prototyping tool used by engineers and even large corporations.

ESP32CAM is the first widespread Open Source Hardware project and was set up to build a community that could help spread the use of the tool and benefit from contributions from hundreds of people who helped debug the code, write examples, create tutorials, supports other users on the forums and build thousands of groups around the globe. We are eternally grateful for being supported by such an amazing community.

Since the ESP32CAM project's foundation, many new development boards and software libraries have been introduced, expanding the range of possibilities available to the community. Today, more than a decade later[12][13], ESP32CAM continues to provide open source hardware and software to bring new ideas to life.
The openness and ease-of-use of the project has led to mass adoption of micro-controller based electronics projects and was a catalyst in the creation of the Maker Movement. ESP32CAM has become the number one choice for electronics makers, especially for developing solutions for the IoT marketplace, which has been predicted to become a $6 trillion market by 2021.

Code:

```
#include "esp_camera.h"
#include <WiFi.h>
#include <TCP.h>
#include <ESPWebServer.h>
```

2. **ESP32CAM Wifi Module**

- ESP32CAM embedded, Xtensa® single-core 32-bit LX6 microprocessor, up to 160 MHz
- +19.5 dBm output at the antenna ensures a good physical range
- Sleep current is less than 20 µA, making it suitable for battery-powered and wearable-electronics applications

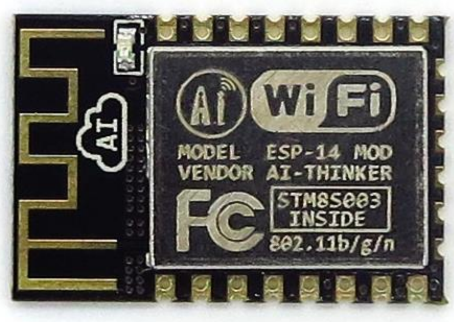


Figure 3.4.2: ESP32 Wi-Fi Module

- Peripherals include UART, GPIO, I2C, I2S, SDIO, PWM, ADC and SPI
- Fully certified with integrated antenna and software stacks
- **The ESP32CAM** series, or family, of Wi-Fi chips is produced by Espressif Systems, a fabless semiconductor company operating out of Shanghai, China. The ESP32CAM series presently includes the ESP32CAMEX and ESP8285 chips.

Code:

```
const char* ssid = "MyWiFiCar";
const char* password = "12345678"
```

- **ESP32CAMEX** (simply referred to as ESP32CAM) is a system-on-chip (SoC) which integrates a 32-bit Tensilica microcontroller, standard digital peripheral interfaces, antenna switches, RF balun, power amplifier, low noise receive amplifier, filters and power management modules into a small package. It provides capabilities for 2.4 GHz Wi-Fi (802.11 b/g/n, supporting WPA/WPA2), general-purpose input/output (16 GPIO), Inter-Integrated Circuit (I²C), analog-to-digital conversion (10-bit ADC), Serial Peripheral Interface (SPI), I²S interfaces with DMA (sharing pins with GPIO), UART (on dedicated pins, plus a transmit-only UART can be enabled on GPIO2), and pulse-width modulation (PWM). The processor core, called "L106" by Espressif, is based on Tensilica's Diamond Standard 106Micro 32-bit processor controller core and runs at 80 MHz (or overclocked to 160 MHz). It has a 64 KiB boot ROM, 32 KiB instruction RAM,
- And 80 KiB user data RAM. (Also, 32 KiB instruction cache RAM and 16 KiB ETS system data RAM.) External flash memory can be accessed through SPI. The silicon chip itself is housed within a 5 mm × 5 mm Quad Flat No-Leads package with 33 connection pads — 8 pads along each side and one large thermal/ground pad in the center.
- ESP32CAM based development boards/modules often incorporate a surface-mount PCB module, a on-board USB-to-serial bridge, and breakout to 0.1 inch pitch connections. For example, the NodeMCU Development Kits use Ai-Thinker modules, the Adafruit feather huzzah uses an Ai-Thinker ESP-12S module with a SiLabs CP2104 USB-to-serial bridge chip, and the weme1 version 2.3 uses an Ai-Thinker ESP-12S module with a WinChipHead CH340G USB-to-serial bridge chip. Other development boards don't use an intermediary module and instead directly incorporate the chip itself on-board — for example, WEMOS D1 Mini Pro uses ESP32CAMEX and WEMOS D1 Mini Lite uses ESP8285
- Anywhere we will use it for tracking the geo location by helping of unwirelabs.com

Fig. 3.4.4: Resistor

Theory of operation

The behavior of an ideal resistor is dictated by the relationship specified by Ohm ‘slaw:

$$V = I.R$$

Ohm's law states that the voltage (V) across a resistor is proportional to the current(I), where the constant of proportionality is the resistance (R).

Equivalently, Ohm's law can be stated:

$$I = V/R$$

This formulation states that the current (I) is proportional to the voltage (V) and inversely proportional to the resistance (R). This is directly used in practical computations. For example, if a 300-ohm resistor is attached across the terminals of a12 volt battery, then a current of12 / 300 = 0.04 amperes flows through that resistor.

Relay module

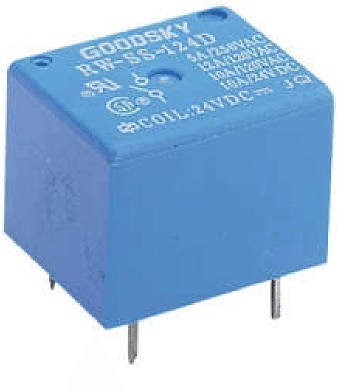
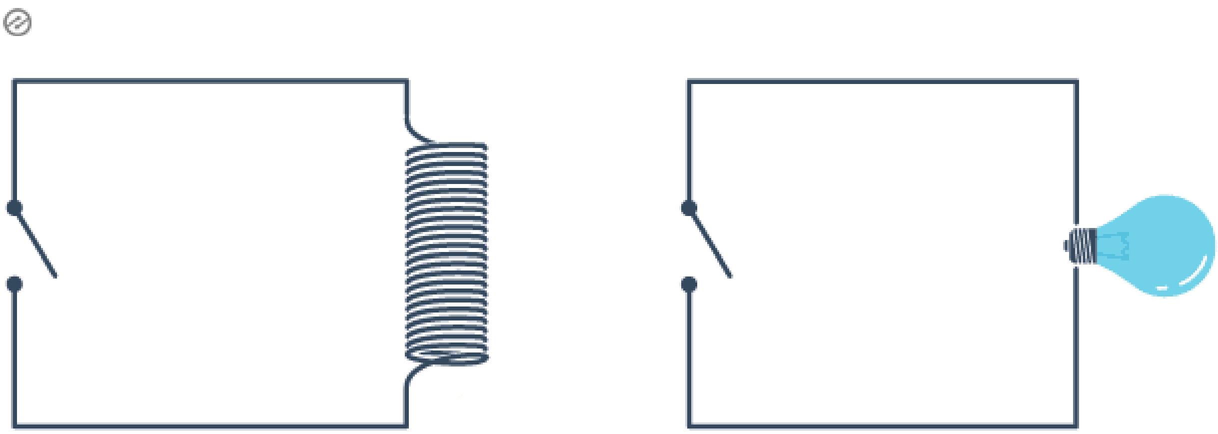


Fig. 3.4.5: Relay

At the core of a relay is an electromagnet (a wire coil that becomes a temporary magnet when electricity is passed through it). A relay can be thought of as an electric lever; you turn it on with a relatively small current, and it turns on another device with a much larger current.

Relay Basics

Here’s a small animation showing how a relay links two circuits together.



To illustrate, think about two simple circuits: one with an electromagnet and a switch or sensor, and the other with a magnetic switch and a light bulb.

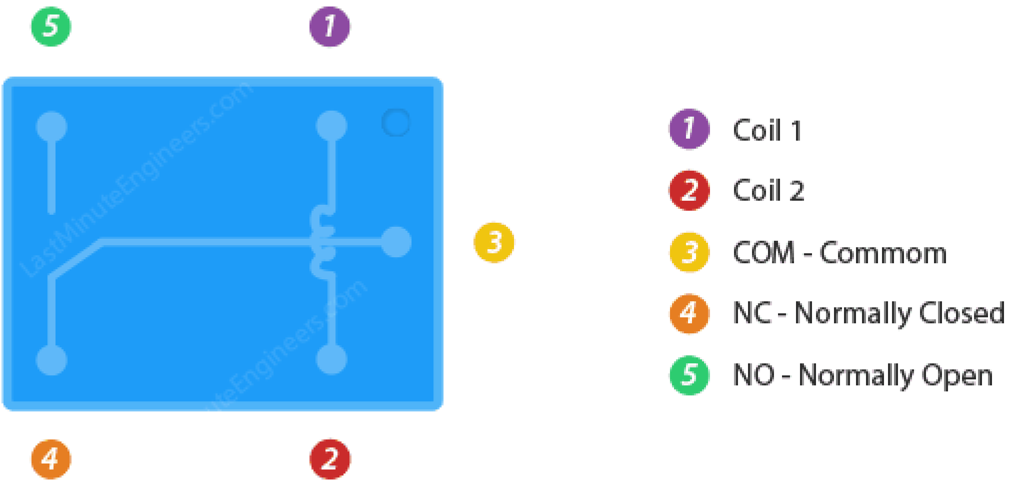
Initially, both circuits are open, with no current flowing through them.

When a small current flows through the first circuit, the electromagnet is energized, creating a magnetic field around it. The energized electromagnet attracts the second circuit's contact, closing the switch and allowing a large current to flow.

When the current in the first circuit stops flowing, the contact returns to its original position, reopening the second circuit.

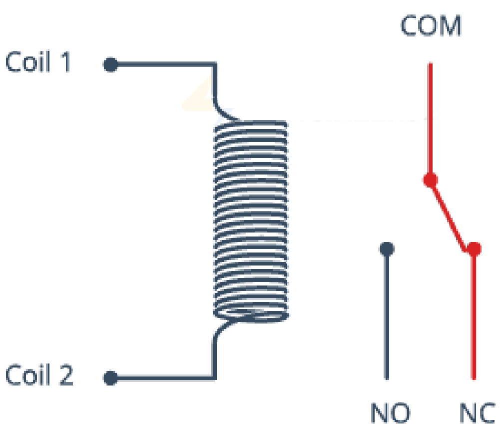
Relay Operation

A relay typically has five pins, three of which are high voltage terminals (NC, COM, and NO) that connect to the device being controlled.



The device is connected between the COM (common) terminal and either the NC (normally closed) or NO (normally open) terminal, depending on whether the device should remain normally on or off.

Between the remaining two pins (coil1 and coil2) is a coil that acts as an electromagnet.



Normally (initial position), the COM terminal is connected to the NC terminal and the NO terminal is open.

SD Card Module

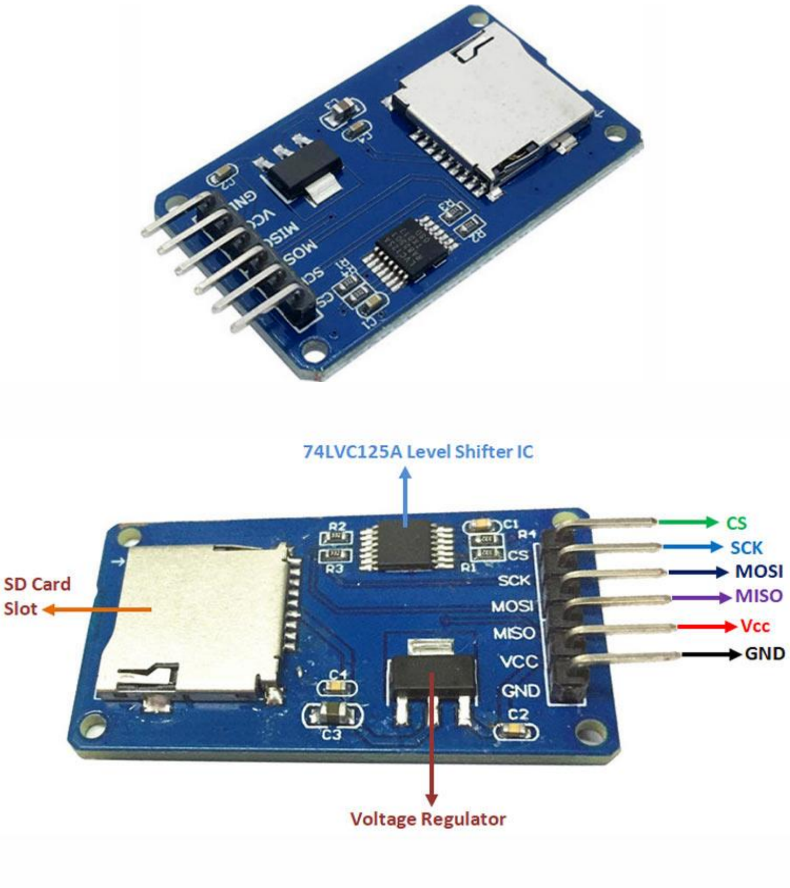


Figure 3.10 Micro SD card modules (MOD100717)

Motor Definition

```
struct MOTOR_PINS {
int pinEn, pinIN1, pinIN2;
};
```

Motor Rotate Function

```
void rotateMotor(int m, int d) {
 digitalWrite(motorPins[m].pinIN1, d == 1);
 digitalWrite(motorPins[m].pinIN2, d == -1);
}
```

Save Image SD Card

```
void saveImageToSD(camera_fb_t *fb) {
 String path = "/image.jpg";
 File file = SD_MMC.open(path, FILE_WRITE);
 if(!file){
 Serial.println("Failed to open file");
 return;
 }
file.write(fb->buf, fb->len);
 file.close();
 Serial.println("Image saved to SD card");
}
```

Micro SD Card Adapter Module
Micro SD Card Adapter Module Pinout

SD cards or Micro SD cards are widely used in various applications, such as data logging, data visualization, and many more. Micro SD Card Adapter modules make it easier for us to access these SD cards with ease. The Micro SD Card Adapter module is an easy-to-use module with an SPI interface and an on-board 3.3V voltage regulator to provide proper supply to the SD card.

Features and Specifications of Micro SD Card Adapter Module

This section mentions some of the features and specifications of the Micro SD Card Adapter Module.

1. Operating Voltage: 4.5V - 5.5V DC
2. Current Requirement: 0.2-200 mA
3. 3.3 V on-board Voltage Regulator
4. Supports FAT file system
5. Supports micro SD up to 2GB
6. Supports Micro SDHC up to 32GB

The module contains 6 pins for power and communicating with the controller. The table below describes the pin type and role of each pin on the module.

Table 3.4.1: Pin Configuration of Micro SD Card Adapter

Pin Type	Pin Description
GND	Ground
VCC	Voltage Input
MISO	Master In Slave Out(SPI)
MOSI	Master Out Slave In(SPI)
SCK	Serial Clock(SPI)
CS	Chip Select(SPI)

Connecting Micro SD Card Adapter Module to an MCU/MPU

A Micro SD Card adapter module can be easily connected to an MCU/MPU. Since the module communicates via the SPI protocol, we need to connect the MISO, MOSI, SCK, and CS of the module to the MCU's.

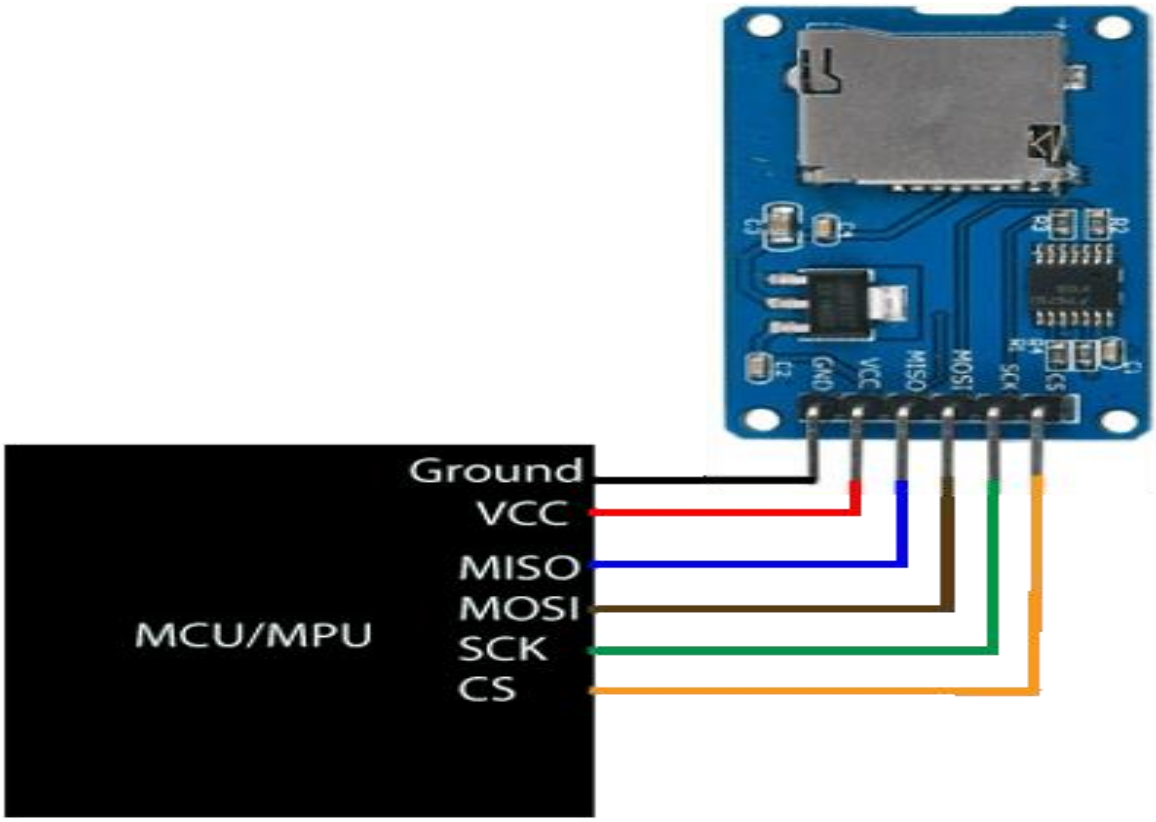


Figure 3.11 SD card holder

The image can be seen as a reference and the connections can be made based upon that. Along with the SD card holder, the module has a 3.3V voltage regulator, along with a 74LVC125A Level shifter IC.

Alternatives for Micro SD Card Adapter Module

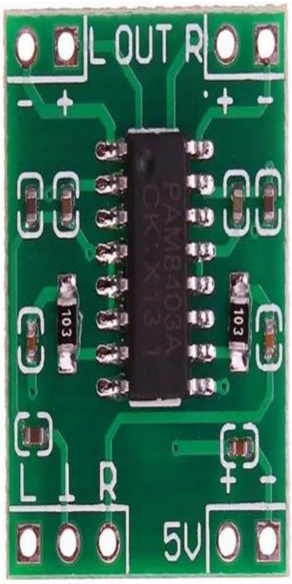
MOD100717 Micro SD card module, Mini Micro SD Card Reader Module

Applications of Micro SD Card Adapter Module

Here are some of the applications of the Micro SD Card Adapter Module.

1. Data loggers
2. Audio, Video storage, and Visualization
3. Expandable memory

PAM8403 Amplifier Circuit Module:



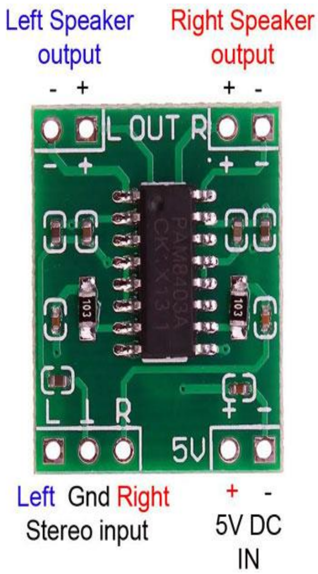


Figure 3.12 Amplifier Circuit Module (PAM8403)

Car move

```
void moveCar(int v) {
  if(v==UP) rotateMotor(0,1), rotateMotor(1,1);
  else if(v==DOWN) rotateMotor(0,-1), rotateMotor(1,-1);
  else rotateMotor(0,0), rotateMotor(1,0);
}
```

PAM8403 Stereo Audio Amplifier Module
PAM8403 Stereo Audio Amplifier Pinout

PAM8403 is an Amplifier Board which can be powered using simple 5V input and could drive two **3W + 3W stereo speakers**. It is an excellent choice, who wants a **Class-D stereo audio amplifier** in small board space. This Amplifier allows the user to achieve high-quality audio reproduction from a stereo input. Additionally, it has a special feature that is, it can drive speakers directly from its output.

Table 3.4.2: Pin Description of PAM8403 Amplifier Board

Pin Name	Description
L	Audio Jack (TRS-Tip) Left Channel Input
Gnd	Audio Jack (TRS-Sleeve) Ground Channel Input
R	Audio Jack (TRS-Ring) Right Channel Input
5v(+)	5v DC Power VDD
5v(-)	5v DC Power GND
L(+)	Left Channel Positive Output
L(-)	Left Channel Negative Output
R(+)	Right Channel Positive Output
R(-)	Right Channel Negative Output

Alternatives for PAM8403: PAM8406, TDA7265

Other Audio Amplifier ICs: LM386, LM380, LM4871, TDA2030, LM1875

Features of PAM8403 Amplifier Board

- Operating Voltage: Wide power supply ranges from 2.5V to 5.5V DC
- Dual-channel stereo with high output power (3W+3W Output at 10% THD with a 4Ω Load @5v DC)
- Max Gain 24 dB.
- Filter less architecture
- Low Quiescent Current and Low EMI
- Operating Temperature: -40 to +85°C
- Short Circuit Protection
- Thermal Shutdown
- Superior Low Noise
- Efficiency up to 90%
- Dimensions (LxWxH) in cm 2.1 x 1.8 x .3
  Note: Complete technical details can be found in the **PAM8403 Datasheet** linked at the bottom of this page.

PAM8403 Amplifier Board

The main power Amplifier IC is the PAM8403, as you can see, the below image other than the IC, the module consists of a few components like capacitors and resistors.

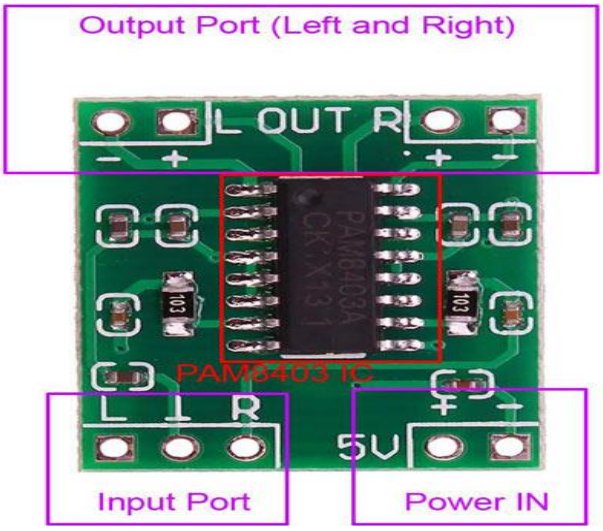


Figure 3.13 Amplifier IC is the PAM8403

The PAM8403 amplifier board is a dual-channel (stereo) amplifier that produces **6W** (3W+3W) output. As any major amplifier system needs to have short circuit protection, PAM8403 has inbuilt short circuit protection that is essential for trouble-free operations.

PAM8403 Amplifier IC itself does not require any kind of heat sink, so this will be a perfect choice for custom speaker projects. It can directly drive **4Ω or 8Ω** speakers. It is mandatory to use a proper speaker with not more than a 3W output rating [14],[15].

As this is a stereo amplifier board, the input section has two input L (Left) and R (Right) with a common ground in between them. Use any kind of audio input that needs to be amplified and it will produce **3W + 3W** audio output.

This amplifier module provides a maximum gain of **24 dB** with **10% THD** at 5V DC input and 4 Ohms load output. It does not require heatsink which also saves additional board space. Irrespective of the heatsink, it could also provide thermal protection which is another essential feature for such a small wattage amplifier module.

PAM8403 Amplifier Board Interfacing Diagram

Circuit diagram for interfacing with two 3W speakers with the PAM8403 Amplifier Board is given below. The PAM8403 Amplifier Board can be powered using any voltage ranging from 2.5V to 5V DC. But it is recommended to use 5V input for maximum output performance.

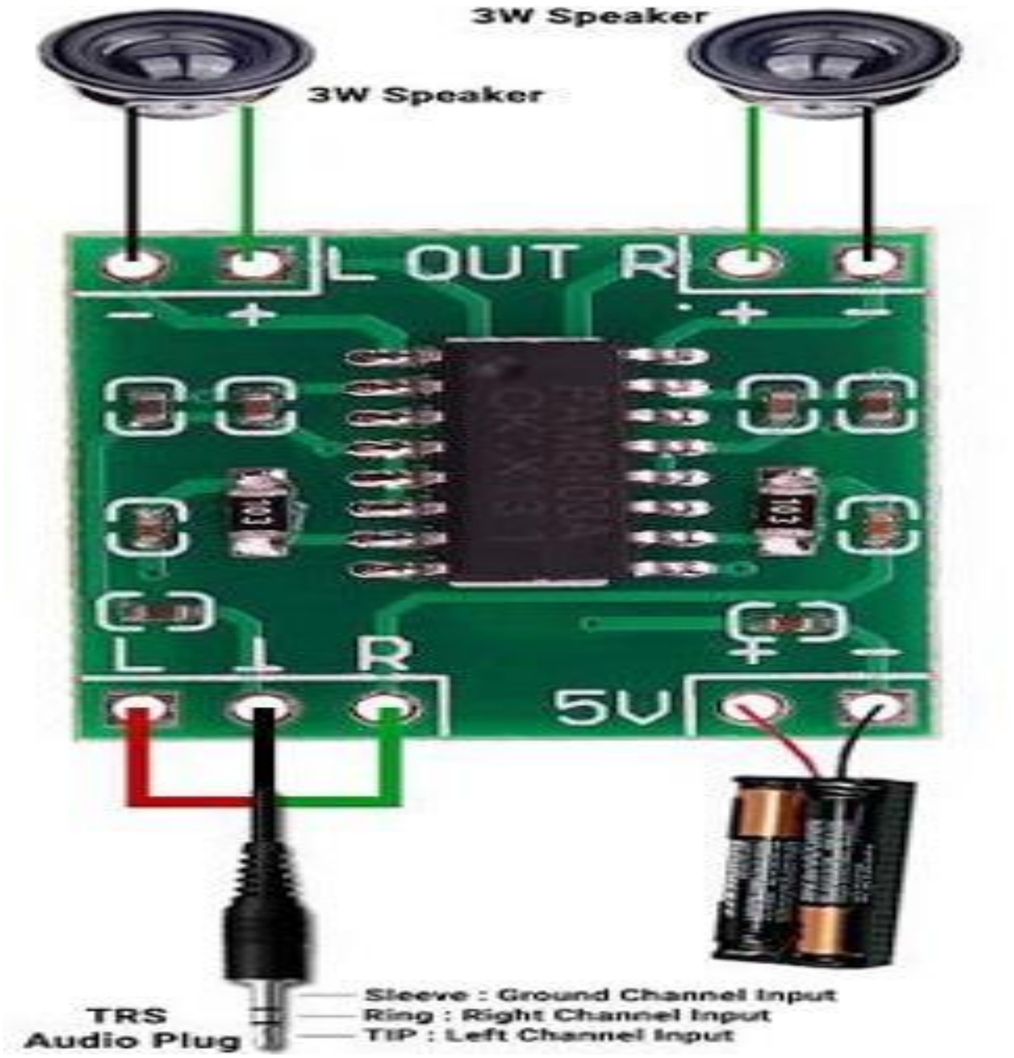


Figure 3.14 Amplifier Board with 3W speakers (PAM8403)

Applications of PAM8403 Amplifier Board

- Speaker output in LCD Monitors / TV Projectors
- Speaker output amplifier in Notebook Computers
- Can be used for Portable Speakers, Portable DVD Players, Game Machines
- Any possible amplifier-based project where small space and 5V output is available

3.5 Software Requirements

1. Arduino Software IDE.
2. Proteus

3.5.1 ESP32CAM software

The smart microcontroller unit named as ESP32CAM Uno can be programmed with the ESP32CAM software. There is no any requirement for installing other software rather than ESP32CAM. Firstly, Select "ESP32CAM Uno from the Tools , Board menu (according to the microcontroller on your board).The IC used named as ATmega328 on the ESP32CAM Uno comes pre burned with a boot loader that allows you to upload new code to it without the use of an external hardware programmer.

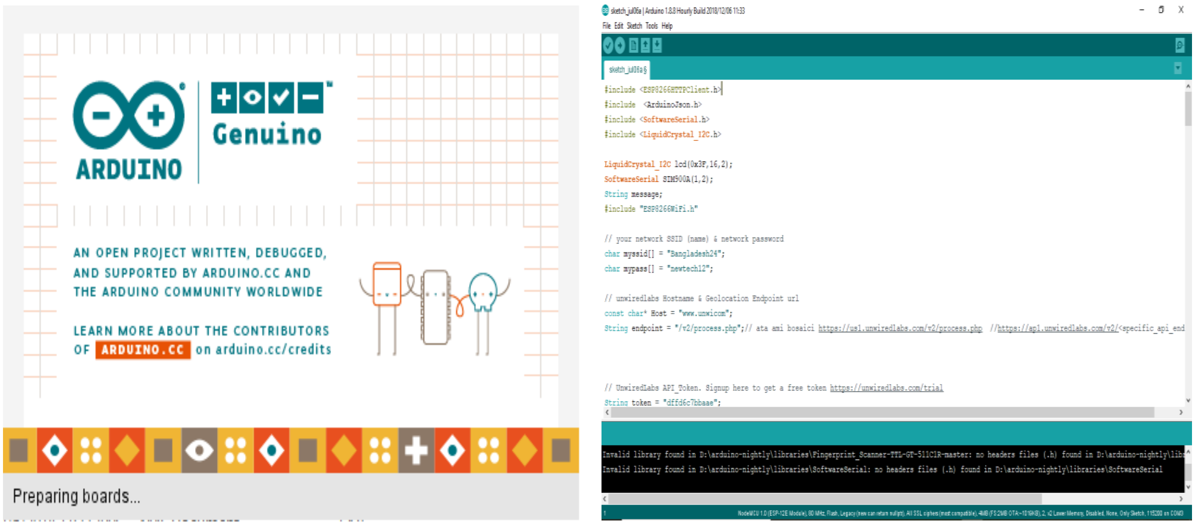


Figure 3.5.1: Arduino Software IDE working Interface

Communication is using the original STK500 protocol (reference, C header files). We can also bypass the boot loader and programs the microcontroller through the ICSP (In Circuit Serial Programming) header. The ATmega16U2 (or 8U2 in the rev1 and rev2 boards) firmware source code is available. The ATmega16U2/8U2 is loaded with a DFU boot loader, which can be activated by:

On Rev1 boards: connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2. On Rev2 or later boards: there is a resistor that pulling the 8U2/16U2 HWB line to ground, making it easier to put into DFU mode.

The ESP32CAM Uno is one of the latest smart microcontroller units and has a number of facilities for communicating with a computer, another ESP32CAM, or other microcontrollers. The ATmega328 provides UART TTL at (5V) with serial communication, which is available on digital pins 0 -(RX) for receive the data and pin no.1 (TX) for transmit the data. An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, an .inf file is required.

The ESP32CAM software includes a serial monitor which allows simple textual data to be sent to and from the ESP32CAM board.

The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial Communication on pins 0 and 1). A Software Serial library allows for serial communication on any of the Uno's digital pins. The ATmega328 also supports I2C (TWI) and SPI communication. The ESP32CAM software includes a Wire library to simplify use of the I2C bus. ESP32CAM programs are written in C or C++ and the program code written for ESP32CAM is called sketch. The ESP32CAM IDE uses the GNU tool chain and AVR Lab to compile programs, and for uploading the programs it uses argued. As the ESP32CAM platform uses Atmel microcontrollers, Atmel's development environment, AVR Studio or the newer Atmel Studio, may also be used to develop software for the ESP32CAM.

3.5.2 Proteus

The Proteus Design Suite is a proprietary software tool suite used primarily for electronic design automation. The software is used mainly by electronic design engineers and technicians to create schematics and electronic prints for manufacturing printed circuit boards. The first version of what is now the Proteus Design Suite was called PC-B and was written by the company chairman, John Jameson, for DOS in 1988. Schematic Capture support followed in 1990, with a port to the Windows environment shortly thereafter. Mixed mode SPICE Simulation was first integrated into Proteus in 1996 and microcontroller simulation then arrived in Proteus in 1998. Shape based auto routing was added in 2002 and 2006 saw another major product update with 3D Board Visualization [15],[16]. More recently, a dedicated IDE for simulation was added in 2011 and MCAD import/export was included in 2015. Support for high speed design was added in 2017.Feature led product releases are typically biannual, while maintenance based service packs are released as required.

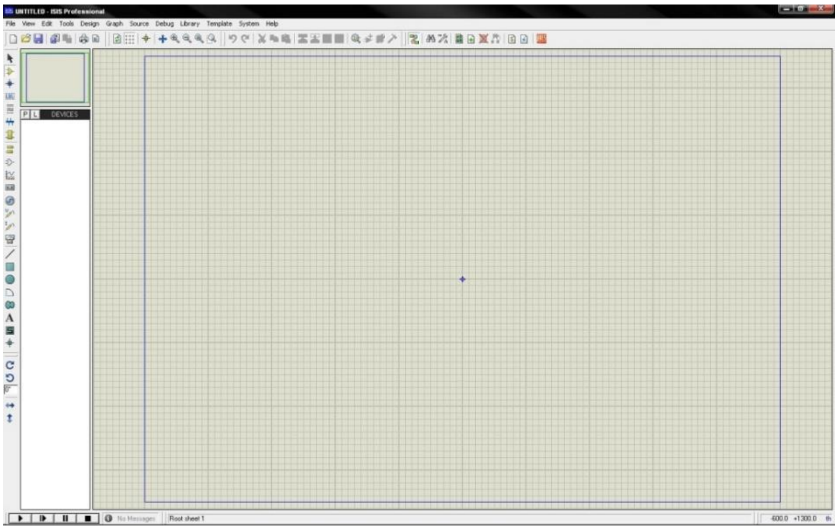


Figure 3.5.2: Proteus Software Interface

Microcontroller Simulation

The micro-controller simulation in Proteus works by applying either a hex file or a debug file to the microcontroller part on the schematic. It is then co-simulated along with any analog and digital electronics connected to it[16],[17]. This enables its use in a broad spectrum of project prototyping in areas such as motor control, temperature control and user interface design. It also finds use in the general hobbyist community and, since no hardware is required, is convenient to use as a training or teaching tool. Support is available for co-simulation of:

- Microchip Technologies PIC10, PIC12, PIC16, PIC18, PIC24, dsPIC33 Microcontrollers.
- Atmel AVR (and ESP32CAM), 8051 and ARM Cortex-M3 Microcontrollers
- NXP 8051, ARM7, ARM Cortex-M0 and ARM Cortex-M3 Microcontrollers.
- Texas Instruments MSP430, PICCOLO DSP and ARM Cortex-M3 Microcontrollers.
- Parallax Basic Stamp, Free scale HC11, 8086 Microcontrollers.

CHAPTER 4
DESIGN AND DEVELOPMENT

4.1 System Design

Over the years, academic and industrial research in robotic fire response has evolved from basic fire detection systems to completely integrated autonomous platforms, indicating a progressive shift toward multi-functional solutions capable of complex environmental interaction. Traditional fire detection research primarily focused on individual sensors such as smoke, infrared heat detectors, and flame sensors, each with limitations in accuracy when used in isolation; consequently, multi-sensor fusion approaches have been proposed in literature to increase reliability and minimize false alarms in dynamic environments where temperature and particulate conditions vary unexpectedly. As robotics technologies matured, wheeled and tracked fire response robots began gaining attention, especially in industrial safety studies, demonstrating the potential for machines to enter hazardous zones too dangerous for humans. Research has underscored the importance of robust mobility systems—such as 4-wheel drive and articulated tracks—to ensure terrain adaptability, particularly when navigating debris, stairs, or uneven surfaces during emergency scenarios. Parallel advancements in microcontroller and embedded systems research have introduced low-cost, high-functionality modules like the ESP32 series; the ESP32-CAM, in particular, has been widely explored for its integrated Wi-Fi and camera support, enabling direct visual feedback without additional communication modules. However, literature also cautions engineers about challenges associated with bandwidth, latency, and environmental interference in wireless video transmission, especially when dense smoke or structural barriers are present. Real-time video streaming research further demonstrates the need for efficient compression and adaptive streaming protocols to maintain clarity and responsiveness over unstable wireless links. Complementing these studies, mobile application interface research highlights user experience optimization, showing how mobile access point (AP) modes remove dependency on external infrastructure and enable direct robot-to-device communication in isolated fire sites. Actuation systems for firefighting mechanisms, examined in robotics and fluid mechanics literature, explore the design of water pump motors capable of delivering adequate pressure and flow rates for effective suppression, with focus on safety interlocks and sensor-driven control logic to prevent unintended activation. Supporting systems like flash lighting and auditory alerts have roots in human factors research, illustrating how enhanced visibility and multi-modal warnings improve situational awareness for both operators and bystanders. Power supply and battery management research emphasizes the importance of energy optimization, where rechargeable Li-ion/LiPo solutions combined with smart charging circuits extend operational uptime and introduce safety protections against overcharge or thermal runaway. Systems integration challenges are a recurring theme in the literature, with studies detailing the complexity of harmonizing sensing, actuation, communication, power, and control into a cohesive architecture that remains maintainable and modular for future enhancements. Comparisons across existing robotic platforms provide performance benchmarks on metrics such as response time, detection accuracy, traversal capability, and communication latency—guiding design trade-offs for reliability and user control. Additionally, human-robot collaboration research suggests that robots can serve as initial responders or reconnaissance units, offering critical intelligence while reducing human exposure to heat and smoke, provided that intuitive interfaces and dependable data streams are in place. Looking ahead, emerging trends in autonomous navigation, AI-based fire prediction, environment mapping, and adaptive suppression strategies hold promise for next-generation systems capable of learning and responding to complex fire dynamics with minimal human input, signaling a future where robotic firefighting plays a central role in emergency management and safety infrastructure.

The methodology for developing the Multifunctional Fire Fighting Robot Car with Live Streaming involves a structured process of system conceptualization, component integration, and iterative validation to ensure functional coherence and reliability. Initially, requirements were defined based on the key functionalities: real-time visual feedback, remote control mobility, fire detection and response, alert notification, and autonomous operation with rechargeable power. The hardware selection phase focused on choosing suitable modules that balance cost, performance, and compatibility—such as the ESP32 CAM for its dual capabilities of wireless connectivity and camera integration, brush DC motors with motor driver for four-wheel locomotion, flame and temperature sensors for reliable detection, a compact pump motor for extinguishing action, and auxiliary components like a speaker and high-intensity LED for alerts and visibility[18][19]. Once selected, electronic interfacing and circuit design were performed, followed by PCB prototyping and power management integration using a rechargeable battery system with charging circuitry. Parallel to hardware assembly, software development involved programming the ESP32 to handle sensor data processing, motor control algorithms, camera streaming, and communication protocols to interface with a mobile application operating in access point mode. The mobile app was developed to provide intuitive controls for navigation, real-time video feed, and status alerts when fire is detected. System calibration ensured sensor thresholds were optimized to activate the pump motor and alarm with minimal false triggers. Finally, iterative testing and field validation were conducted to evaluate robot responsiveness, communication stability, and overall performance in simulated fire conditions, leading to refinements that improved operational effectiveness and safety.

4.2 Block Diagram

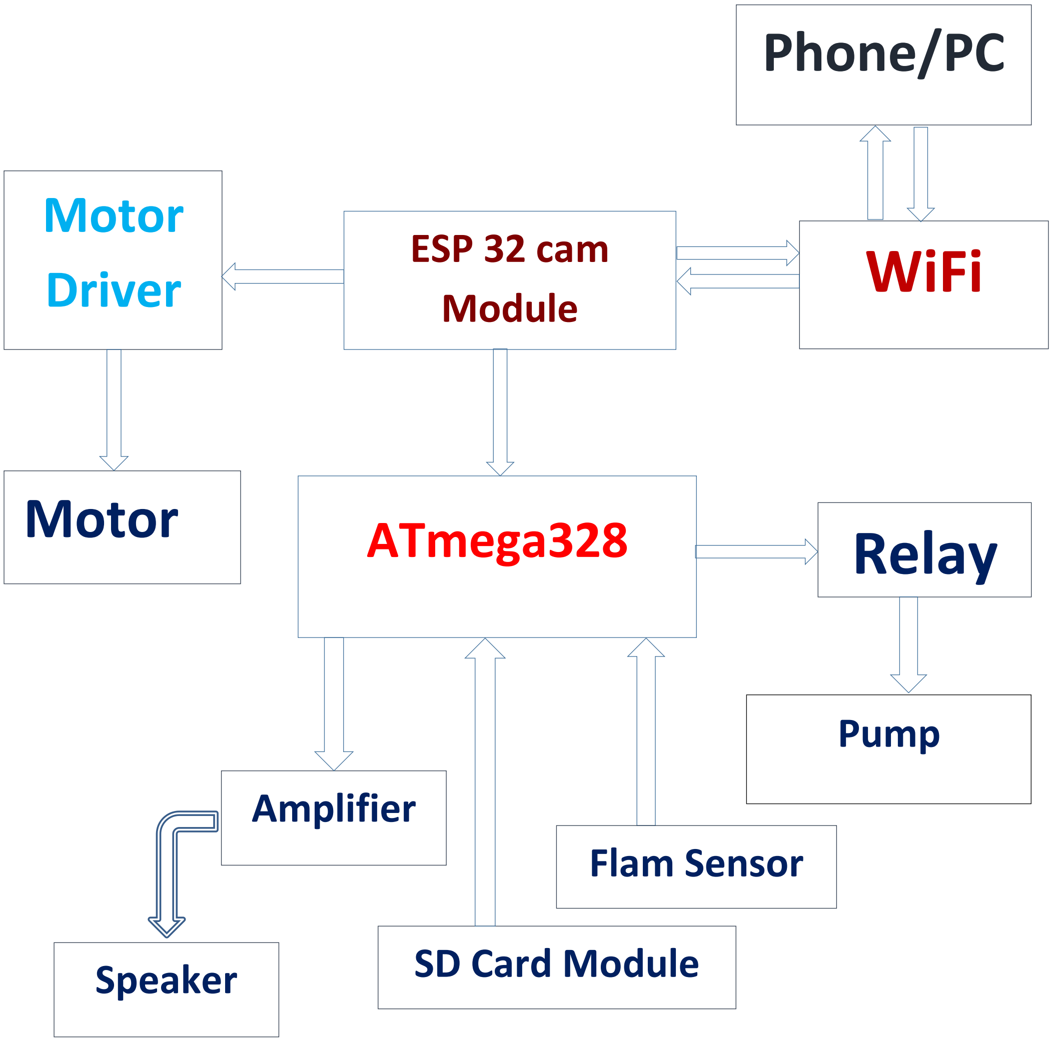


Figure 4.2: Block Diagram

4.3 Flow Chart

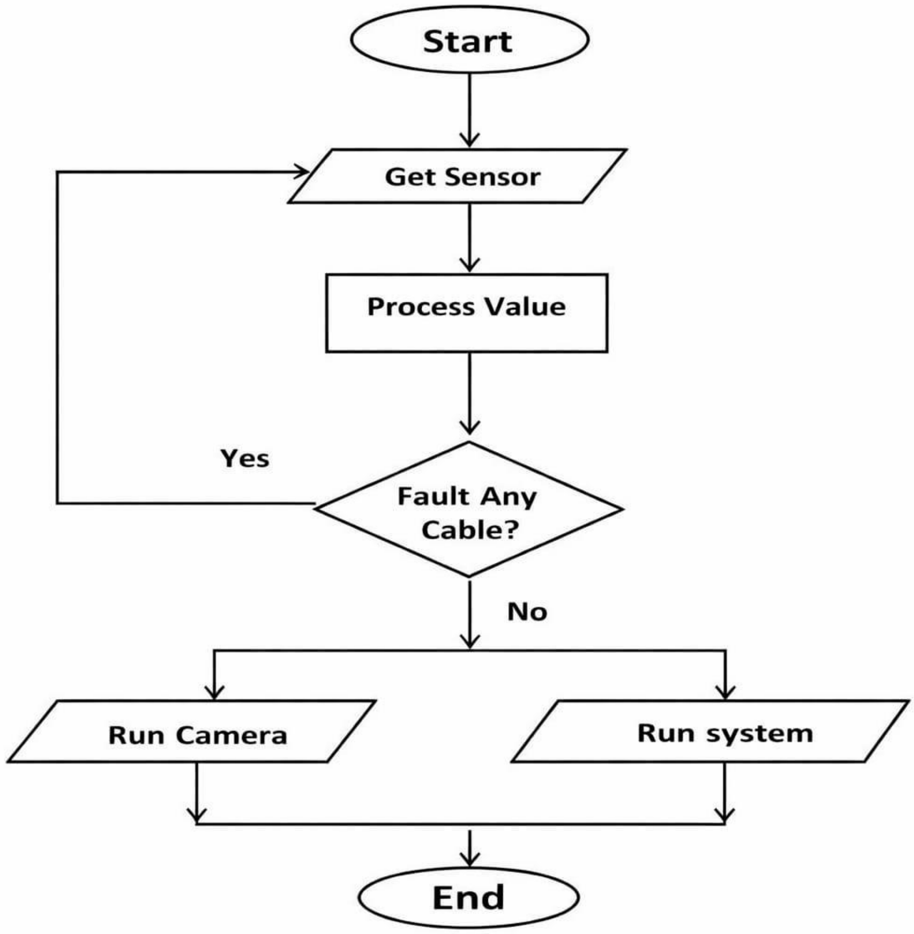


Figure 4.3: Flow Chart Design

4.4: Circuit Diagram

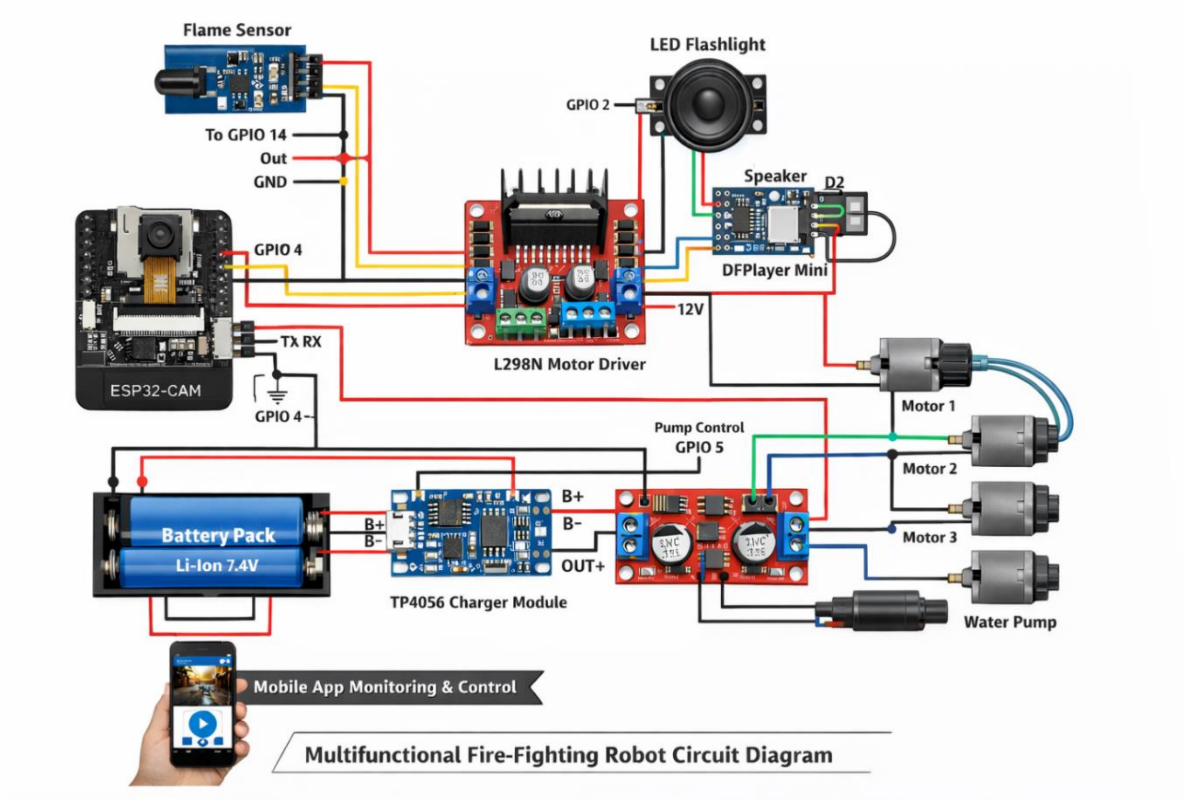


Figure 4.4: Circuit Diagram of the project

4.5 Working Procedure

The operation of the Multifunctional Fire Fighting Robot Car begins with system initialization, where the ESP32-CAM module and Arduino Nano boot up and establish communication with the mobile application in access point (AP) mode. The ESP32-CAM continuously streams live video to the mobile app, providing a real-time visual feed of the robot's surroundings to the operator. Simultaneously, all sensors are activated; flame and temperature sensors constantly monitor environmental conditions to detect any fire presence. When the sensors detect a fire exceeding predefined thresholds, the Arduino Nano immediately triggers the speaker system through the DFPlayer Mini module to emit an audible alarm, alerting nearby personne[20],[21]l. The ESP32 simultaneously processes sensor signals to initiate automatic responses or waits for operator commands from the mobile interface. The 4-gear motors, controlled via the L298N motor driver, receive input from the ESP32 to maneuver the robot toward the detected fire source, navigating obstacles and uneven terrain efficiently. Upon reaching the target, the ESP32 activates the pump motor to discharge water or extinguishing agent through the mounted nozzle, while the high-intensity LED flash light is turned on to improve visibility in smoke-filled or dim environments. Throughout the operation, power management is handled by a rechargeable Li-ion battery and a TP4056 charging module, ensuring uninterrupted performance and protecting sensitive electronics from over-voltage or over-current situations. The robot's movement, pump operation, light control, and sensor feedback are all coordinated to allow real-time adjustments based on live video and environmental readings. The operator can manually override or refine the robot's actions via the mobile application, enabling precise control in complex or confined spaces. After the firefighting operation is complete, the robot can be navigated back to the charging station, where the integrated charging system replenishes the battery for future use. Regular monitoring, calibration of sensors, and maintenance of motors and pump are recommended to ensure the reliability and longevity of the system. By combining live visual feedback, remote control, sensor-driven automation, and active firefighting mechanisms, the robot ensures both effective fire suppression and safety for human operators in hazardous scenarios.

CHAPTER 5

IMPLEMENTING AND TESTING

5.1 Implementation of the project

The implementation of the Multifunctional Fire Fighting Robot Car involves a systematic integration of hardware and software components, following a stepwise approach from design to functional testing. The first step involves assembling the mechanical structure: a robust 4-wheel chassis is chosen for stability and mobility across uneven or debris-laden surfaces, with four gear motors mounted to provide independent torque control for smooth maneuvering. Wheels are aligned, and proper mounting ensures minimal vibration, which is crucial for stable camera operation. After chassis assembly, electronic components are installed, starting with the ESP32-CAM, which serves as the brain for live video streaming and communication with the mobile application in access point (AP) mode. Parallelly, the Arduino Nano is integrated into the system to control the speaker system, which is responsible for triggering audible alarms when fire is detected. Sensors, including flame and temperature modules, are mounted at the front or elevated positions to maximize fire detection coverage. Sensor outputs are wired to the ESP32 and Arduino Nano, with proper voltage regulation to protect sensitive electronics. The L298N motor driver is connected to the ESP32 and the four gear motors, enabling bidirectional control for forward, backward, and turning maneuvers. The water pump motor is mounted on a stable platform and connected through the motor driver for controlled activation. Power supply implementation involves a rechargeable Li-ion battery pack, coupled with a TP4056 charging module, which supplies consistent voltage to the motors, sensors, ESP32, and Arduino Nano, ensuring uninterrupted operation.

Once hardware integration is complete, software development begins. The ESP32 firmware is programmed to handle real-time video capture, Wi-Fi streaming, motor control, and sensor data acquisition. Sensor thresholds are calibrated to detect fire accurately and minimize false triggers, while motor speed and direction algorithms ensure smooth navigation. The Arduino Nano is programmed to respond to sensor triggers by activating the DFPlayer Mini to play the preloaded alarm sound. The mobile application is developed to provide a user-friendly interface for remote robot control, allowing users to steer the robot, activate the water pump, switch on the LED flashlight, and view live video feedback. After individual modules are tested, system-level integration is performed to ensure seamless interaction between all components. Testing includes navigation over obstacles, fire detection in controlled conditions, simultaneous operation of pump, light, and alarm, and real-time monitoring via the mobile application. Any issues, such as motor lag, sensor misreadings, or communication latency, are corrected iteratively. Finally, safety checks are conducted, including battery monitoring, overheating prevention, and emergency stop functionality. The implemented system successfully demonstrates an autonomous, remotely controlled, multifunctional firefighting robot capable of live monitoring, fire detection, alerting, and active suppression, representing a comprehensive solution for enhancing fire safety and reducing human exposure to hazards.

5.2 Results picture of the project

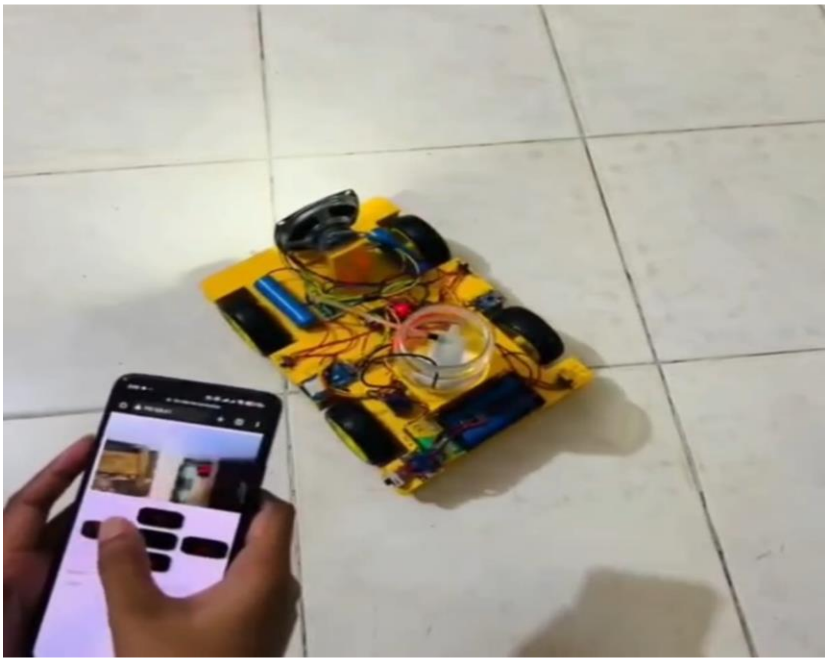


Figure5.2.1: A

This is a fire-fighting robot that is controlled by a mobile phone. When the left button is pressed on the phone, the robot moves to the left. It is used to go near fire and help in extinguishing it using water or foam.

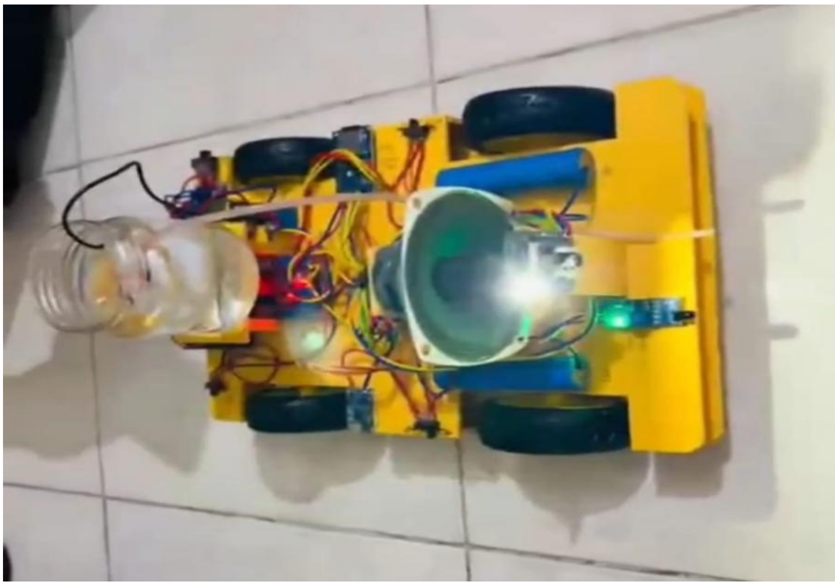


Figure 5.2.2: B

This is a fire-fighter robot car. The robot is turned on using a switch, and the flashlight is controlled by a mobile phone. The light's brightness can be increased or decreased from the phone, which is the main feature shown here.

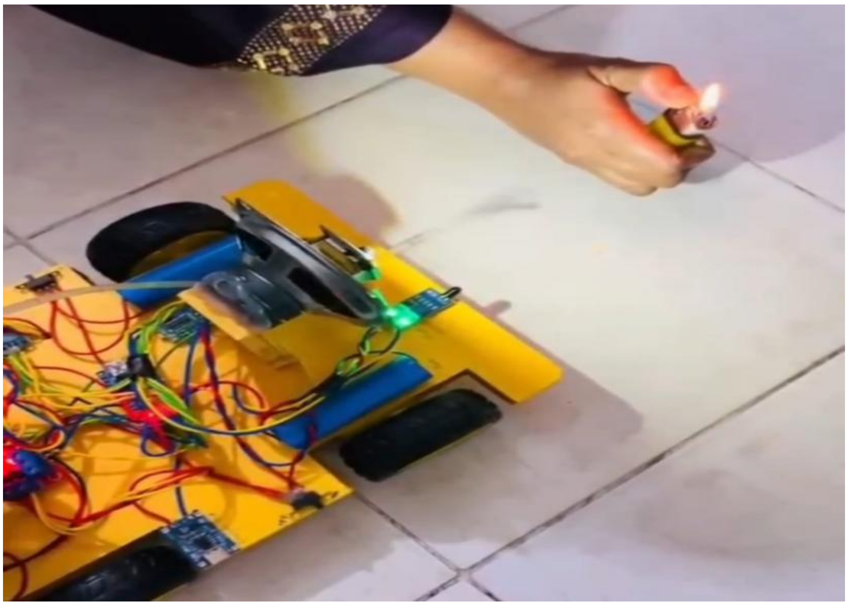


Figure 5.2.3: C

Here, the fire sensor detects the flame, then it alerts through a speaker, and after that the water pump sprays water to extinguish the fire automatically.

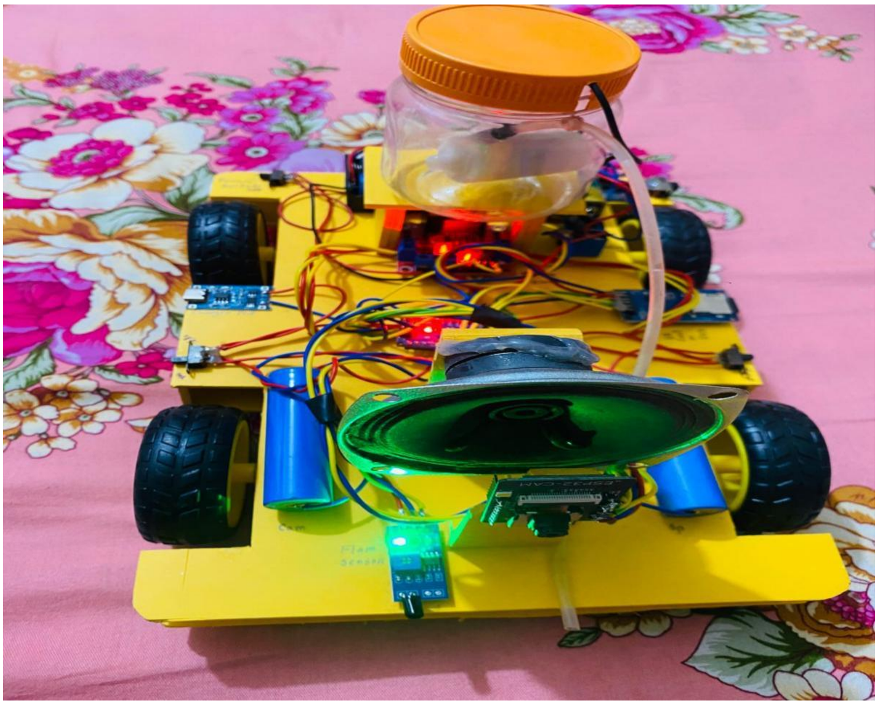


Figure 5.2.4: D

The image shows a fire-fighting robot car equipped with a water tank, pump, and flame sensor. It uses wheels for movement and electronic components to detect fire and spray water automatically

CHAPTER 6
DISCUSSION AND CONCLUTION

6.1 Discussion

The Multifunctional Fire Fighting Robot Car demonstrates the effective integration of robotics, IoT, and embedded systems to enhance fire safety operations. During testing, the robot showed efficient maneuverability across uneven surfaces and obstacles, thanks to the 4-wheel gear motor setup and well-calibrated motor control algorithms. The ESP32-CAM provided real-time video streaming to the mobile application with minimal latency, allowing operators to monitor fire scenarios remotely and make informed decisions. The integration of flame and temperature sensors proved reliable, triggering the pump motor and alarm system promptly upon detecting fire, which highlights the effectiveness of sensor threshold calibration. The Arduino Nano-controlled speaker system successfully emitted audible alerts, ensuring human presence in the vicinity was informed in a timely manner. The LED flash light improved visibility in low-light and smoke-filled conditions, enhancing both live video clarity and on-ground operations. The rechargeable battery system provided sufficient power for continuous operation, and the charging module ensured safe recharging, demonstrating good energy management. Some challenges were observed, such as occasional motor lag under maximum load and slight fluctuations in video frame rate in high-smoke environments, which can be addressed in future iterations with higher torque motors and optimized compression algorithms for streaming. The system's modular design allowed for easy troubleshooting and replacement of components without affecting overall functionality. Overall, the project validates that a combination of real-time monitoring, sensor-driven automation, and active firefighting mechanisms can significantly reduce human exposure to hazardous situations, improve response time, and enhance situational awareness. The discussion highlights the practicality, safety benefits, and effectiveness of implementing IoT-enabled robotics in emergency response while pointing out areas for potential improvement, such as autonomous navigation, AI-based fire prediction, and extended battery life for prolonged operations.

6.2 Advantages

- ✓ **Enhanced Safety:** Reduces human exposure to fire, heat, smoke, and hazardous environments.
- ✓ **Real-Time Monitoring:** ESP32-CAM provides live video streaming for remote observation and decision-making.
- ✓ **Remote Control Operation:** Mobile application allows operators to navigate the robot from a safe distance.
- ✓ **Rapid Response:** Robot can reach fire sites faster in environments where human access is difficult.
- ✓ **Active Fire Suppression:** Equipped with a pump motor to directly spray water or extinguishing agents.
- ✓ **Audible Alerts:** Built-in speaker system provides instant sound alerts for nearby personnel.
- ✓ **Improved Visibility:** LED flash light enhances vision in smoke-filled or low-light conditions.

- ✓ **Modular Design:** Components like sensors, motors, and electronics can be easily replaced or upgraded.
- ✓ **Rechargeable Battery System:** Provides mobility and sustained operation with safe recharging.
- ✓ **Cost-Effective:** Low-cost microcontrollers (ESP32, Arduino Nano) and easily available components reduce overall project cost compared to industrial firefighting robots.

6.3 Disadvantages

- ✓ **Limited Autonomy:** The robot depends on operator control; fully autonomous navigation is not implemented.
- ✓ **Battery Constraints:** Continuous operation time is limited by battery capacity; long missions may require recharging.
- ✓ **Environmental Limitations:** Dense smoke, high heat, or water exposure may affect sensors and electronics.
- ✓ **Motor Load Limitations:** Gear motors may struggle on very rough terrains or heavy obstacles.
- ✓ **Signal Range Dependency:** Wi-Fi-based communication range limits operation distance from the operator.
- ✓ **Water Pump Capacity:** Small pump may be insufficient for large fires.
- ✓ **Video Quality Fluctuations:** Wi-Fi congestion or high interference can cause temporary frame rate drops in live streaming.

6.4 Future Scope

The Multifunctional Fire-Fighting Robot Car has significant potential for future enhancements that can improve its effectiveness, autonomy, and versatility. One major advancement could be the integration of autonomous navigation using obstacle detection sensors and path-planning algorithms, allowing the robot to move to the fire site without manual control. Incorporating AI-based fire prediction and machine learning models can enable the system to detect fire patterns and act proactively, potentially minimizing damage. The robot can be upgraded with thermal imaging cameras to detect hotspots through smoke or walls, improving situational awareness. Swarm robotics could also be explored, where multiple robots work collaboratively to extinguish large fires more efficiently. Battery technology advancements can allow for longer operation times and faster recharging cycles. Adding larger or more powerful pumps can enhance firefighting capacity for industrial or large-area fires. Integration with IoT-based cloud platforms could provide remote monitoring from any location, real-time data logging, and predictive maintenance. Finally, environmental resilience improvements, such as heat-resistant casings and waterproofing, would make the robot suitable for extreme conditions. These upgrades can transform the robot from a prototype into a robust, real-world emergency response solution.

6.5 Conclusion

The Multifunctional Fire-Fighting Robot Car with Live Streaming successfully demonstrates the integration of robotics, sensors, IoT, and embedded systems to enhance fire safety operations. By combining the ESP32-CAM for real-time video streaming, Arduino Nano-controlled speaker system, flame and temperature sensors, four-gear motors, and a water pump motor, the robot provides a comprehensive solution for monitoring, alerting, and actively responding to fire incidents. The mobile application interface in AP mode enables operators to navigate the robot remotely, observe live conditions, and control extinguishing actions, thereby minimizing human exposure to hazardous environments. During testing, the robot showed effective maneuverability, timely fire detection, and coordinated activation of the pump, LED flash light, and speaker alarm, confirming the reliability of the system design. The rechargeable battery system with integrated charging ensures sustained operation, making the robot suitable for repeated or extended use. While minor limitations such as battery capacity, motor load, and Wi-Fi range exist, the overall performance illustrates that combining real-time monitoring, sensor-driven automation, and active firefighting mechanisms can significantly improve response speed, safety, and situational awareness. The modular architecture allows for easy maintenance, component replacement, and future upgrades. In conclusion, the project validates that low-cost, IoT-enabled robotic solutions can supplement traditional firefighting methods, offering safer and more efficient intervention. With further enhancements such as autonomous navigation, AI-based fire prediction, thermal imaging, and swarm coordination, this robot has the potential to evolve into a versatile, scalable, and robust tool for emergency response in both residential and industrial applications, representing a meaningful step toward technology-assisted firefighting solutions.

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