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Arduino-based Firefighting Robot

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Abstract-Accidents caused by fire result in severe damage to life and property, especially in hazardous and hard-to-reach areas. In order to minimize human risk and increase the efficiency of firefighting, a Fire Fighting Robot with ESP32 Camera is proposed and implemented. In this system, the Arduino Uno board is used as a primary controller. The ESP32-CAM is used for live video streaming through a web page for the user. The robot is designed to operate in two modes: manual mode and automatic mode. The modes are selected through a web page. In manual mode, the user controls the robot's movement and views the live video feed. The ultrasonic sensor is used in manual mode for obstacle detection. Four flame sensors are used to detect fire. Once the fire is detected, the robot moves towards the fire source. A DC water pump is used to spray water on the fire and extinguish it. The robot's movement is controlled using DC motors driven by an L298 motor driver. A servo motor is used for direction control of the water pump. A buzzer is used for alarm generation when the fire is detected. The robot is powered using a battery supply regulated using an LM2596 voltage regulator module. This project is a simple and cost-effective way of remote fire detection and firefighting using robotics and wireless monitoring techniques. It is useful for industrial areas, warehouses, and places where human access is hazardous.

Keywords - Firefighting Robot, Autonomous Fire Suppression, Arduino- Based Robot, ESP32-CAM, Remote Monitoring.

I. INTRODUCTION

Fire accidents are one of the major hazards responsible for damaging human life, property, and the environment. In many situations such as industrial plants, warehouses, and hazardous environments, it is difficult and dangerous for firefighters to approach the fire source. For minimizing human risk and to improve firefighting efficiency, robots can be used to detect and extinguish fire. The Fire Fighting Robot with ESP32 Camera is a robotic system for detecting fire and conducting firefighting operations using a mobile phone through a web interface. The system consists of an Arduino Uno microcontroller as a main controller to integrate all sensors and actuators. An ESP32-CAM module is also included for live video streaming to enable users to observe their environment and control the robot remotely using a web browser on a mobile phone. The system can work in two operating modes: manual and automatic, which can be selected through a web page. In manual mode, users can control the robot's movement by observing live images from the ESP32 camera. An ultrasonic sensor (HC-SR04) is also included for detecting obstacles during manual navigation. The system also includes flame sensors for detecting the presence of fire. Once fire is detected, the robot moves towards the fire source and sprinkles water to extinguish it through a water pump connected to a relay. The movement of the robot is performed by two DC motors connected to an L298 motor driver, and a servo motor is included for adjusting the direction of water spray. A buzzer is also included to indicate alarm signals for detecting fire. The system is powered by a battery supply through a voltage regulator module (LM2596). This project presents a low-cost and efficient robotic system for assisting firefighting operations by minimizing risk to human life.

II. LITERATURE SURVEY

Researchers have proposed various robotic systems for fire detection and firefighting. These systems aim to improve safety and response time in case of fire. Various researchers have proposed fire-fighting robots using microcontrollers and flame sensors for fire detection and water pumps for fire extinguishing. These systems can detect and extinguish fire automatically. However, the proposed systems did not allow for the remote monitoring of the fire-fighting robot. Various researchers proposed wireless-controlled fire-fighting robots, which allow users to control the robot from a distance using RF or Bluetooth communication. However, these systems did not allow for real-time video streaming of the fire environment. Recently, researchers proposed embedded systems and IoT technologies, which allow for the integration of cameras and web-based control systems. Researchers proposed fire-fighting robots using Wi-Fi-enabled modules such as ESP8266 and ESP32. These modules allow for real-time video streaming and mobile device-based control. Various researchers proposed ESP32-CAM-based robotic systems for fire-fighting, which allow for real-time video streaming and fire detection using sensors. Based on the above discussion, the proposed Fire Fighting Robot with ESP32 Camera integrates flame sensors, ultrasonic sensors, and live video streaming for manual and automatic control. This system improves the accuracy of fire detection, real-time video streaming, and the flexibility of the robot compared to existing fire-fighting robot systems.

III. METHODOLOGY

3.1 System Architecture

The proposed system architecture of Fire Fighting Robot includes a central control unit and various integrated subsystems that work in concert to detect, monitor, and extinguish fire in an efficient manner. The system architecture includes an Arduino Uno as the central control unit and an ESP32-CAM module for wireless video streaming and remote control.

The system architecture includes the following major subsystems:

Fire Detection System

The system includes multiple flame sensors fixed at different points on the robot to detect the presence and direction of fire. Once a flame is detected, signals are sent to the Arduino Uno control unit, and it processes the signals to take appropriate action.

Monitoring and Communication System

The ESP32-CAM module in the system includes a wireless camera that provides live video streaming through a web interface. This enables users to monitor the environment and control the system using a mobile phone or web interface. This system is extremely useful in taking decisions in a hazardous environment in real time.

Robot Movement Control System

The movement of the robot is controlled using a DC motor and an L298N motor driver module. The system also allows manual mode using a web interface and automatic mode in which the robot will move towards the fire on its own.

Fire Extinguishing System

The system includes a DC water pump connected to a relay module. The pump is used to spray water on the fire once it is detected using the ultrasonic sensor HC-SR04. The water flow is controlled using a servo motor to target the exact point where the fire is located.

Alert and Indication System

A buzzer is included in this system to give an alert sound whenever fire is detected.

Power Supply System

The system is powered using a battery as a power source. An LM2596 voltage regulator module is used to regulate the voltage in order to operate all the devices in the system.

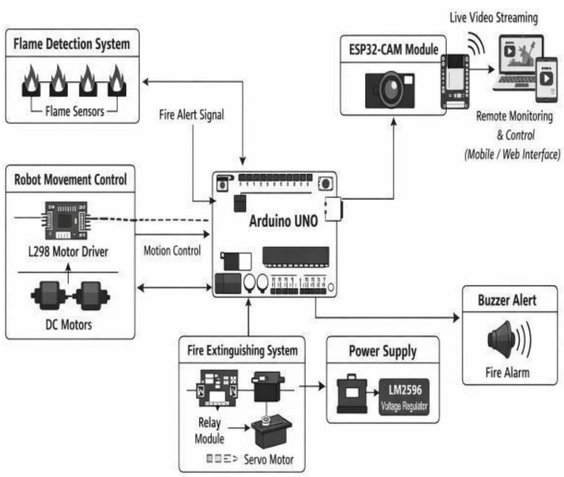

Figure 1: Fire Fighting Robot System Architecture

Fig 1: Fire Fighting Robot System Architecture

3.2 Working Principal

The Fire Fighting Robot works on the principle of using various sensors, controllers, and actuators to detect the fire and perform firefighting operations in an efficient manner. The Fire Fighting Robot uses a rechargeable battery to perform all the operations. The constant voltage is provided by an LM2596 voltage regulator. The microcontroller used in this robot is an Arduino microcontroller, which acts as the main processor and receives information from all the sensors and controls all the connected devices. The Fire Fighting Robot works in two modes: manual mode and automatic mode. The mode selection is done using a web page. The Fire Fighting Robot works in the following manner: in the manual mode, the Fire Fighting Robot is moved using a mobile phone or a browser, and at the same time, the surroundings are observed using live video streaming provided by the ESP32-CAM module. The ESP32-CAM captures the surroundings and provides the live visuals to the user wirelessly. The Fire Fighting Robot also provides obstacle detection in the manual mode using an ultrasonic sensor. The Flame sensor continuously detects the presence of fire. As soon as the flame sensor detects the flame, it sends a signal to the microcontroller. The microcontroller then moves towards the location of the fire using DC motors and a motor driver circuit. After reaching the location of the fire, the relay module is turned on using the microcontroller, and water is sprayed using the water pump to extinguish the fire. The flow of water is also controlled using a servo motor. Meanwhile, a buzzer is turned on to indicate that the fire has been detected and the Fire Fighting Robot is working..

3.3 Hardware Components

Arduino Nano

Arduino Nano is a small microcontroller board based on ATmega328. It is used as a controlling unit for the entire system. It processes the sensor values and controls the motor, relay, etc.

ESP32-CAM

ESP32-CAM is a Wi-Fi camera used for live video streaming. It helps the user to see the robot's condition using a mobile phone or any browser.

Flame Sensors

Flame sensors are used for detecting fire. They sense the presence of fire using infrared light. They send signals to the microcontroller when they find fire.

L298N Motor Driver

L298N is a dual H-bridge motor driver used for controlling the direction and speed of DC motors. It helps the robot move forward, backward, left, and right.

IV. Motors

V. motor is used for the movement of the robot. It converts DC

voltage into rotational motion for the robot's movement.

Relay Module

The Relay module is used as a switch for the water pump. It is used to turn the water pump either ON or OFF using a digital signal.

Servo Motor

Servo motor is used for controlling the direction of water spray. It helps the robot target the fire more accurately.

Water Pump

Water pump is used for sprinkling water on the fire. It is turned ON using a digital signal sent by the flame sensor.

Buzzer

The buzzer is used for alerting the user. It produces sound when activated.

LM2596 Voltage Regulator

LM2596 is a DC-DC converter used for voltage regulation. It provides a constant voltage supply to the entire system.

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Battery

Two 4V rechargeable batteries are used as a power source for the entire system. These two batteries are connected together in series for efficient Operation.

3.4 Software Implementation

The software aspect of the system has been created using the Arduino IDE, which allows for writing, compiling, and uploading of the program to the microcontroller. Control logic was programmed in embedded C for controlling how the sensors worked with each other, as well as how they interacted with their actuators and their respective communication interfaces.

The main program was executed by the Arduino Nano by continually polling the flame and ultrasonic sensors; based on that sensor data, the Arduino controlled the motion of the robot, the activation of the buzzer, and the operation of the water pump using the relay to switch on and off the pump.

With respect to the ESP32-CAM module, it is programmed to act as a web server and enable the live feed from the camera to be viewed by the user via an internet connection (Wi-Fi). The ESP32-CAM generates a web-based interface that allows the user to see the live feed and send commands to control the robot via the Internet.

The software system provides the overall system with the ability to coordinate between the hardware elements and gives the ability for real-time monitoring/remote control and for the automatic response to the detection of a fire.

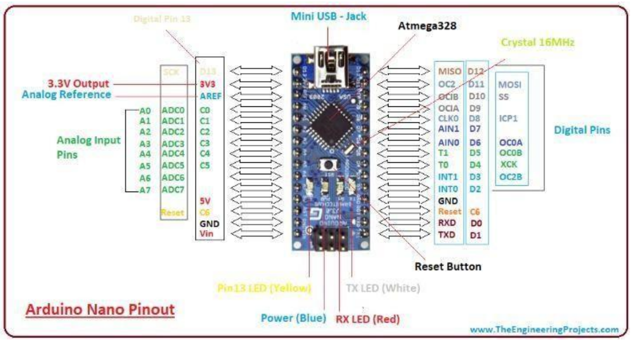

Fig 2: Arduino Nano Architecture Diagram

3.5 Robot Operation Modes

This robot is equipped to work in two ways, either in manual mode or in automatic mode. These two modes can be chosen by a user utilizing the web-based interface built into the ESP32- CAM module. In manual operation, a user will operate the robot directly with either a mobile device or through their web browser. The ability to watch live video, allows the user to view their environment and move the robot accordingly. Additionally, an ultrasonic sensor is built into the robot to assist the user in avoiding obstacles, giving the user a safer movement while manually using the robot. During automatic operation, the robot will run without any user interaction. The robot will continuously monitor for any flames using flame sensors. If the flame sensors detect a flame, the robot will automatically run to the flame, once reaching the flame the system will activate the water pump so as to extinguish the flame. These two modes of operation, allow a user to control the robot when needed and/or allow the robot to operate autonomously based on the circumstances.

3.6 Fire Detection Mechanism

The process of detecting and extinguishing the fire is achieved using a flame sensor, a microcontroller, and an actuation mechanism. The flame sensor is employed to sense the surroundings and detect the existence of a fire using the reflected light from the flames. The sensor then sends a signal to the microcontroller.

Subsequently, the microcontroller receives the signal and responds by sending a command to the robot to move towards the location of the fire using DC motors. This allows the robot to get close enough to extinguish the flames.

Concurrently, the microcontroller switches ON the relay module, which then switches ON the water pump to spray water on the flames and extinguish them. A servo motor is employed to change the direction of the water flow.
Moreover, a buzzer is also employed to alert the system of the existence of a fire using the flame sensor. This mechanism allows the robot to detect and extinguish the flames in an efficient manner.

3.7 Power Supply System

All of the robot's electrical components need to receive electrical energy in order for all parts of the entire system to work, which is provided by the power source system. The power source system uses rechargeable batteries as its main power source so that the robot can be easily transported and used for remote applications.

The output from the power supply is converted from battery power to regulated DC power using an LM2596 DC–DC buck converter. Regulated DC voltage is required to provide stable and appropriate voltage levels to a variety of

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devices, thereby preventing damage to sensitive modules and providing consistent performance.

The microcontroller, sensors, motor driver, ESP32-CAM module and other devices receive regulated DC voltage that results from the DC– DC converter's output from the battery. Therefore, a dependable power supply is necessary for the robot to operate reliably, especially when it is moving, communicating and doing so in a manner that will result in a successful firefighting operation.

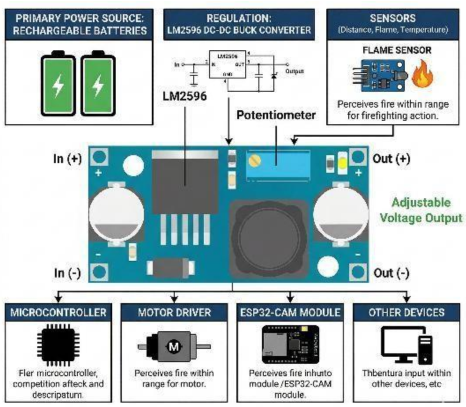

Fig 3: Power supply system

3.8 Robot Control System

The robot movement control system is designed to facilitate the movement of the robot using DC motors and a motor driver module. The DC motors are connected to the wheels of the robot, enabling it to move in both forward and reverse gears. The DC motors are driven using an L298N driver module, which serves as an interface between the Arduino Nano and the motors.

The L298N driver module is designed to operate using the H-bridge principle, which allows the flow of electric current to be reversed in the DC motor. This is achieved by changing the polarity of the voltage applied to the terminals of the DC motor, thereby enabling it to move in different directions. This allows the robot to move in different directions, including forward, reverse, and turning.

The movement of the DC motor is achieved using electromagnetic principles. The DC motor is designed to operate using the interaction between the magnetic field and the flow of electric current. The interaction between the magnetic field and the flow of electric current allows the DC motor to move. This phenomenon can be expressed as:

$$V = IR + E$$

In this equation, V is the voltage applied to the motor, I is the current flowing through it, R is the armature resistance, and E is the back electromotive force developed in the motor.

The speed of the motor is controlled using Pulse Width Modulation (PWM). In this method, the average voltage supplied to the motor is changed using a variable duty cycle method. The voltage in this method is defined as:

$$V_{PWM} = \frac{D}{100} \times V_{max}$$

In this equation, D is the duty cycle and Vmax is the maximum voltage supplied to the motor. By increasing or reducing the duty cycle, the speed of the robot is controlled efficiently.

The Arduino Nano produces a Pulse Width Modulation voltage and digital signals, which are sent to the motor driver IC. Using this method, the motor movement is controlled efficiently.

The above equation shows that the system used to control the movement of the robot is a combination of a DC motor and an H-bridge motor driver with Pulse Width Modulation voltage control.

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3.9 Flame Detection System

The flame detection system is used for detecting the presence of fire. The system receives inputs from the control unit. The flame detection system uses several flame sensors attached to the robot. The sensors are capable of detecting fire from any direction. The sensors are sensitive to a particular wavelength of light, which is present during a fire.

Each of the flame sensors is constantly monitoring the surroundings. The sensor sends a signal when it finds a flame. The signals from all the sensors are received by the Arduino Nano. The Arduino Nano processes the information received from the sensors and determines the presence of fire.

The input received from the sensors can be explained as:

$$F(t) = \{f1(t), f2(t), \ldots, fn(t)\}$$

where $fi(t)$ represents the output of the ith flame sensor at time t.

If there is no fire, the robot is in monitoring mode. When any of the sensors receive a fire signal, it sends the information to the control unit. The control unit takes further actions.

The flame detection condition can be represented as:

$$\text{Fire Detected} = \begin{cases} 1, & \text{if any } f_i(t) \text{ exceeds threshold} \\ 0, & \text{otherwise} \end{cases}$$

The output from the sensors can be either analog or digital. The output can be analog, indicating the intensity of the fire. The output can also be a digital signal, indicating the presence of fire. Thus, the flame detection system helps the robot to identify the presence of fire. The robot can start firefighting operations.

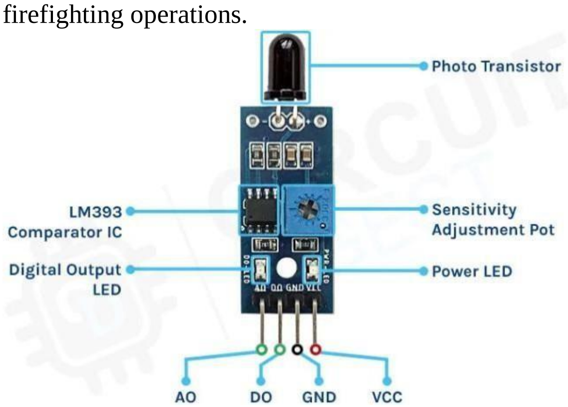

Fig 4: Flame Sensor Module.

3.10 Fire Extinguishing System

The fire extinguishing system is designed to extinguish the detected fire by using a combination of a water pump, a relay module, and a servo motor for directional purposes. This system is immediately implemented after detecting the fire or flame by using the Arduino Nano controller.

Once a flame is detected by the sensors, the system processes this data and determines the direction of the fire or flame. This data is then used to position the servo motor to face the nozzle of the water pump in the correct direction to target the fire or flame. The servo motor angle can be represented by a function of variation in sensor data as follows:

$$\boldsymbol{\theta} = \boldsymbol{g}(\boldsymbol{F})$$

where F represents the flame sensor data, and g(·) represents a function of data variation for determining servo motor angle. This ensures correct positioning of water to target the fire or flame.

The water pump is operated by a relay module. This module is a switching device for operating the water pump. This relay can be represented by a function as follows:

$$R(t) = \begin{cases} 1, & \text{Pump ON (fire detected)} \\ 0, & \text{Pump OFF (no fire)} \end{cases}$$

Once this relay is triggered, the water pump will start spraying water to target the fire or flame. This process will continue as long as there is fire or a flame detected by the sensors.

The water sprayed by the pump is channelled through a nozzle. The rate of water flow can be represented by a function as follows:

$$\boldsymbol{Q} \propto \boldsymbol{P}$$

where P is a function of power supply to the pump. This implies that a higher power supply will result in a greater rate of water flow to target the fire or flame more efficiently.

Thus, the fire extinguishing system provides a reliable and effective mechanism for suppressing fire using controlled water delivery and directional adjustment.

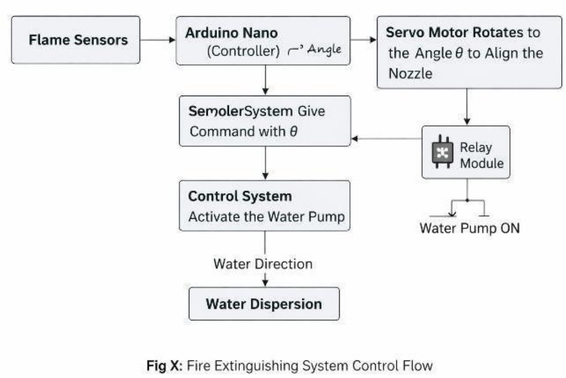

Fig 5: Fire Extinguishing Control Flow.

IV. EMBEDDED SYSTEMS OVERVIEW

An Embedded System is an integrated computer system to perform a defined task as part of another system. An embedded system will include all the hardware and software elements necessary for a single operation to be performed within a given time frame.

A proposed Fire Fighting Robot is an integrated system using an Arduino Nano as the main controller. This microcontroller processes inputs from flame sensors and other devices while providing outputs to control motor (DC), relay, and servo motor to activate a fire detecting device and extinguishing device.

Embedded Systems are described by having real-time response capabilities, reliability, low power consumption, and a primary function defined. This project utilizes sensors, a microcontroller, and communication devices to provide an efficient automated robot to perform operations in hazardous conditions.

V. SOFTWARE ARCHITECTURE

The software architecture for the Fire Fighting robot being developed has been constructed to efficiently co-ordinate the sensing, decision-making, communication and actuation functions based upon the requirements of the system. The software will be developed using the Arduino IDE where the embedded C programming language will be used to execute the control logic and thus manage all the hardware components of the Fire Fighting robot.
The Arduino Nano is the primary micro-controller for the Fire Fighting robot and will halt at each loop cycle to read inputs from flame sensors, ultrasonic sensors, process these input values into a control action response to the motors, relay, servo motor and buzzer through appropriate digital outputs.

The ESP32-CAM is a standalone communication module which will allow for the development of a web page user interface so that the robot can send live video and will also enable the user to remotely control the movement of the robot via a phone or web browser.

The software will operate in two different modes, user operated (manual) and automatically operated (automatic). In the user operated mode, each time a user command is received through the web interface, the controller will read this command and carry out the control logic associated with that command as per the input received from the sensors. In the automatic mode, the control logic will operate and carry out its functions without further user actions, by continuously checking all the input sensor signals and executing the appropriate control actions for detecting and extinguishing fires, independently of any user controls.

The Fire Fighting robots control system will execute all of the above via the model of real-time execution, whether the input is being continuously checked, decisions are made at that instant in time based upon these inputs.

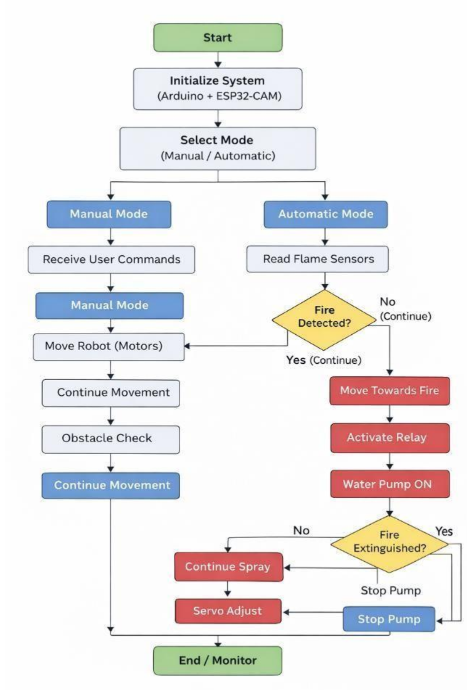

Fig 6: Software Flow chart.

VI. IMPLEMENTATION

Software Implementation

The developed control software for the Fire Fighting robot has been created with an Arduino IDE (Integrated Development Environment). The IDE is used to write, compile and upload the control program to the Arduino Nano microcontroller. The control program has been written using the Embedded C programming language, allowing for an efficient link between the hardware components and the control system.

The Arduino Nano executes the control program in an infinite loop. On each loop, the Arduino Nano reads from the flame sensors and ultrasonic sensors, processes this data and generates the corresponding output signals. With this data, the controller controls the movement of the robot, activates the buzzer and switches on the water pump via the relay module.

The ESP32-CAM module has been programmed separately to enable wireless communication and live video streaming. The ESP32-CAM module allows the user to view the robot's surroundings in real-time via a web-based interface and provide control commands through a mobile device or web browser.

The fire-fighting robot's software supports two modes of operation; manual mode and automatic mode. In manual mode, the user command from the web interface is sent to the control system which processes the command and drives the corresponding motors. In automatic mode, the control system continuously checks for an input signal from the flame sensor, and if there is an input signal (fire), then automatically activates all outputs.

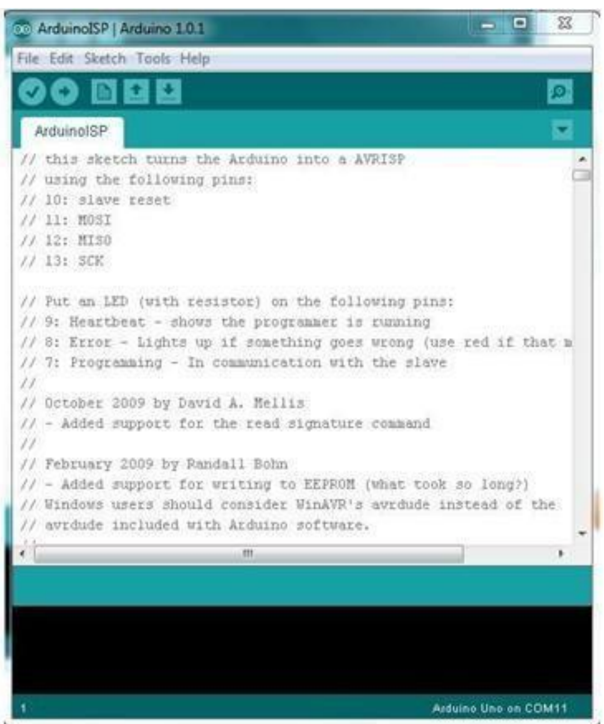

Fig 7: Software Arduino IDE.

Hardware Implementation
The hardware part of the Fire Fighting Robot includes multiple hardware components that work in harmony with one another in order to carry out the operations of fire detection, movement, and extinguishing. The hardware part is centred around the Arduino Nano controller, which is used as a central unit to control all hardware devices connected to it.

The flame sensors used in this project detect the presence of fire in a particular area. These sensors continuously sense the environment and send signals to the controller whenever they detect a flame. An ultrasonic sensor is also used to detect obstacles while the robot is in movement.

The movement of the Fire Fighting Robot is carried out using two DC motors connected to an L298N motor driver. This driver acts as an interface between the Arduino Nano controller and the motor in order to control its movement in different directions. Using this motor driver, the robot is able to move in forward and backward directions and also turn while in movement.

The fire extinguishing mechanism is carried out using a water pump connected to a relay module and a servo motor. The relay module is used to turn ON/OFF the water pump using signals sent from the microcontroller. The servo motor is used to adjust the direction of water spray in order to target the exact location where water is required in order to extinguish the fire.

The ESP32-CAM module is also used in this project in order to carry out live video streaming using a web camera connected to it. This allows the user to monitor the surrounding environment using a web interface and control the movement of the Fire Fighting Robot using this interface.

A buzzer is also connected to this project in order to generate an alert whenever it detects the presence of fire in a particular location. The power supply used in this project is rechargeable battery power connected to an LM2596 voltage regulator in order to regulate voltage supply to all devices connected to it.

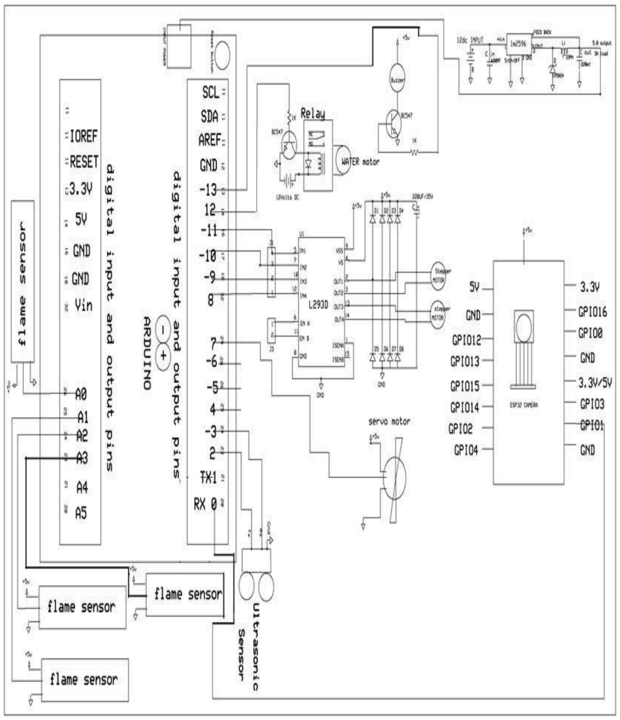

Fig 8: Schematic Diagram of Working Fire Fighting Robot

Fig 9: ATmega328p

VII. ALGORITHMS

Algorithm is a systematic procedure for solving a specific problem or performing a specific task in a system. In the proposed Fire Fighting robot, algorithms play a very important role in controlling the entire operation of the robot and coordinating the activities of all the other parts. Algorithms are the set of rules that describe how the system will process the inputs received from the sensors, make decisions, and execute actions such as movement, fire detection, and extinguishing.

In the proposed project, the algorithm continuously receives data from the flame sensors and checks for the presence of fire. Based on the inputs received, the algorithm checks whether the robot is in search mode or fire extinguishing mode. The algorithm is also responsible for controlling the movement of the robot. It sends the required signals to the motor driver to move the robot in the required direction. This helps in moving the robot towards the fire source when the fire is detected or in searching for the fire when no fire is detected.

In addition to these, the algorithm is also responsible for controlling the operation of the relay and water pump for extinguishing the fire. The servo motor is also controlled by the algorithm to ensure accurate direction of water spray. When the robot is in manual mode, the algorithm receives the inputs from the web interface through the ESP32-CAM module and controls the movement of the robot accordingly.

Overall, the proposed Fire Fighting robot is greatly benefited by the presence of algorithms. Algorithms help in improving the efficiency, reliability, and responsiveness of the system. They ensure real-time operation, reduce the involvement of humans, and provide a systematic way of integrating all the other parts in the Fire Fighting robot.

Algorithm1: Robot operation
function FireFightingRobot();
Input: Flame sensor data F = (F1, F2, F3, F4) System initialized with Arduino Nano, ESP32- CAM, motors, relay, servo
Output: Fire detected and extinguished
Initialize all hardware components;
while true do
Select mode (Manual / Automatic);
if (Manual Mode) then
receiveUserCommand();
moveRobot();

else
F1 ← readSensor(S1);
F2 ← readSensor(S2);
F3 ← readSensor(S3);
F4 ← readSensor(S4);
if (F1 OR F2 OR F3 OR F4 detects fire) then
moveTowardsFire();
θ ← determineServoDirection(F1, F2, F3, F4);
rotateServo(θ);
activateRelay();
while (fireDetected()) do
continue spraying water;
end while
deactivateRelay();
else
searchForFire();
end if
end if
end while end function

2: Navigation and Search

function searchForFire(); Input: No flame detected
Output: Robot scans environment
rotateRobotLeft();
delay(t);
read sensors;
if (fire detected) then
moveTowardsFire();
return;
end if
rotateRobotRight();
delay(t);
read sensors;
if (fire detected) then
moveTowardsFire();
return;
end if
moveForward(); end function

3: Servo direction Control

function determineServoDirection(F1, F2, F3, F4); Input:
Flame sensor values
Output: Servo angle θ
if (left sensor detects fire) then
θ ← 0°;
else if (center-left sensor detects fire) then
θ ← 45°;
else if (center-right sensor detects fire) then
θ ← 135°;
else if (right sensor detects fire) then
θ ← 180°;
else
θ ← 90°; // default position
end if
return θ;
end function

4: Water Pump Control

function controlWaterPump();
Input: Fire detection signal Output: Pump ON/OFF
if (fireDetected()) then
activateRelay();
turnPumpON();
else
deactivateRelay();
turnPumpOFF();
end if
end function

Algorithm5: ObstacleAvoidance

function obstacleAvoidance();
Input: Ultrasonic sensor data Output: Safe movement
distance ← readUltrasonic();
if (distance < threshold) then
stopRobot();
turnRight();
else
moveForward();
end if
end function

VIII. SOFTWARE COMPONENTS

There are many different modules in the software that help to structure the robot's functionality and to enable a more organized and efficient manner for the robot to function. The sensor reading module analyses information collected by the flame sensors. The movement control module specifies the manner in which the robot moves; for instance, sending motor commands to the function of moving a wheel of the robot. The servo control module is responsible for the ability of the robot to turn the water nozzle. The relay modules are responsible for turning on and off the water pump.

In addition to these modules, the overall system has been designed to provide additional modules. These modules allow for a continuous state of monitoring for fire alarms and continued navigation during the operation of each robot. In addition, the remaining modules allow the robot to follow commands received through a web interface such as turning, stopping, and completing other commands. A modular design for the robot's software will lead to an increased level of stability and reliability within the software systems as well as make it easier to run/execute a program.

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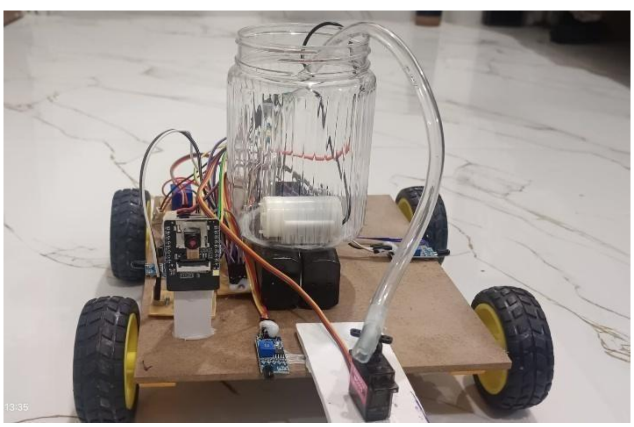
IX. RESULTS & DISCUSSION

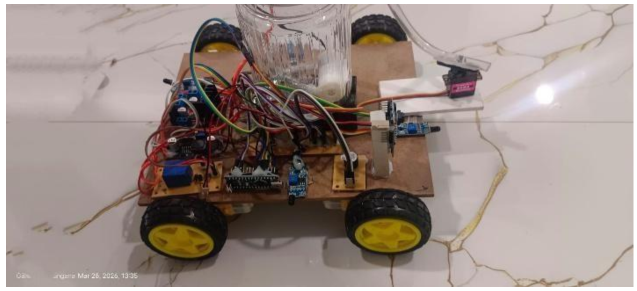
After investigating and making changes, it has been revealed that the design and implementation of the firefighting robot with ESP32-camera was successfully accomplished by being able to detect fires and help put out fires. The firefighting robot system includes an Arduino, ESP32-CAM module, flame sensor, ultrasonic sensor, motor driver, and water pump to detect fires and put them out. Experimental results indicate that robot is able to successfully move, detect fires and spray water onto the area where the fire originated from.

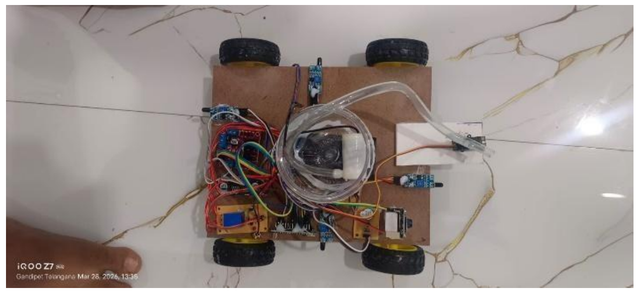
The ESP32-CAM module has successfully allowed for live video streaming through a web page, allowing the user to view what the robot sees in real time using a mobile phone or computer. The user also had the ability to choose between manual or automatic operation modes, as well as controlling the movement of the robot through this web interface.

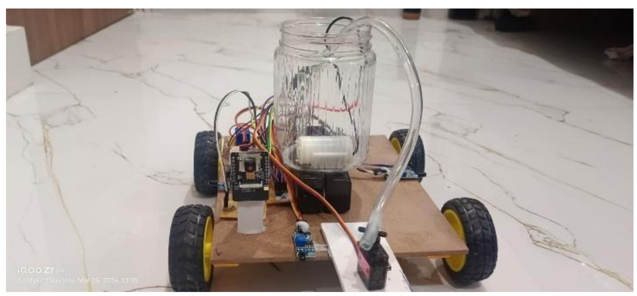
Users were able to control forward, backward, left, and right movement of the robot through manual mode while viewing the video feed. The ultrasonic sensor (HC-SR04) allowed for detecting obstacles and helping the user while moving.

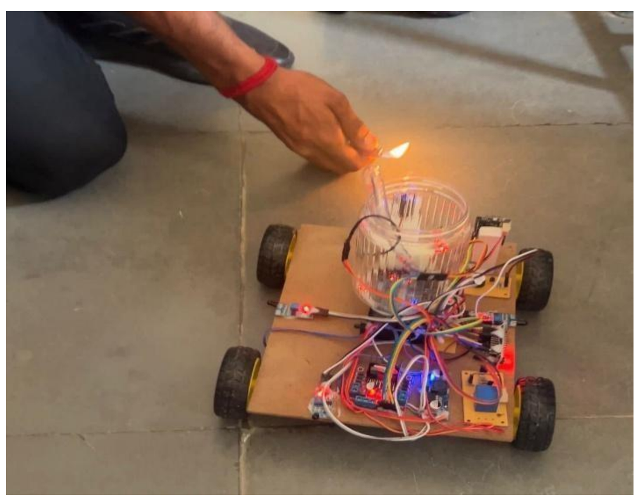
The flame sensors were able to detect fire at a close distance, once detected the robot was able to move toward the fire and activate the DC water pump via the relay to extinguish the fire.

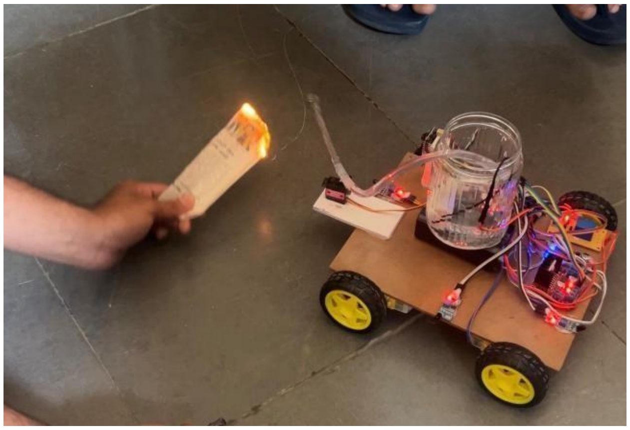


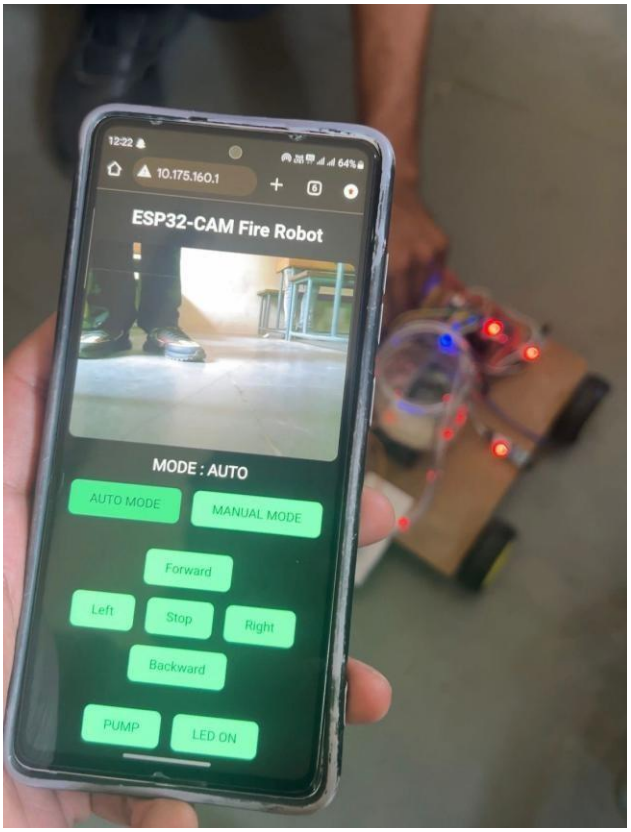












X. CONCLUSION

The robotic Fire Fighting system with the ESP32-CAM is a functional, economical, and efficient robotic system designed to assist in the detection of fire and extinguishing fire to ensure the least risk of injury or loss of life to persons involved. The robotic Fire Fighting system is designed using various components including Arduino Nano, flame sensors, ultrasonic sensors, and ESP32-CAM module, DC motors, relays, servo motors, and a water pump, to allow the Fire Fighting robotic system to carry out firefighting operations as required by multiple different users.

The Fire Fighting style has two styles that can be used, Manual and Automatic. Manual allows the user to control the Fire Fighting robot remotely through the internet via a web interface and allows the users to view video streaming, which provides situational awareness or a graphical representation of what is occurring in the environment. Automatic enables the robot to detect fire using flame sensors, in which the robot navigates to the location of the fire and activates the fire extinguishing system without any human direction.

The use of a wireless communications method using the ESP32-CAM allows for the user to have access to the Fire Fighting robot using their mobile device and provides the highest level of user-friendliness and system accessibility. The use of sensors, control algorithms and actuation systems allows the Fire Fighting robot to respond and effectively operate in an environment that is dangerous.

This project illustrates the effective use of embedded systems, robotics, and IoT technologies in improving fire safety and emergency response. The developed robotic firefighting system can be used in manufacturing, warehouses, and other high-risk environments where it would be dangerous to enter.

XI. FUTURE SCOPE

The ESP32 Camera Fire Fighting Robot comes with many options to add advanced technology to enhance its capabilities, making it more versatile and quality of services. Future enhancements could include adding artificial intelligence and image processing capabilities to help automatically detect fire/smoke through ESP32 camera rather than by using a flame sensor alone. If a thermal camera were also added to the robot, it could be used in conjunction with the flame sensor or alone in the detection of fire/smoke even when there are dark or smoky conditions. This addition would provide the robot with better abilities to find areas with hidden fire sources. Fully autonomous navigation systems for the robot could also be added into the design using advanced sensors such as LIDAR or new advanced obstacle detection systems would allow them to navigate independently without the need for manual intervention. Increasing the water supply capacity of the robot's (or adding a fire extinguisher system) would also assist the use of larger firefighting capabilities. The presence of GPS and IoT cloud technology would allow for monitoring and control from a distance for any fire operation. Implementation of this type of technology would allow for efficient operations in large industrial environments as well as rapid emergency response. Multiple robots could also be designed to work collectively to optimize and enhance performance.

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