CHAPTER

Intelligent autopilot fire extinguishing robot

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8.1 Introduction

In the last two decades, the purpose of robots in industries in automating industrial processes has been extended. The processes include fabrication, finishing, transferring, and assembling parts; distribution of finished products; picking, sorting, packaging, and palletizing products in manufacturing and material handling units. Numerous studies have shown that robots can be beneficial in aerospace, automotive, computers, e-commerce, medicine, rehabilitation, rescue operation, and industry. Industrial robots are multifunctional manipulators designed for more specialized materials, divisions, gadgets, or devices through various programmatic movements to perform various tasks. Still, there is a demand for a system that can control, communicate, and integrate different robots regardless of their types and specifications per Fourth Industrial Revolution (4IR) standards.

Recently, machine learning has also heated up interest in robotics to increase the intelligence of robots and the productivity in industry to reduce cost. Researchers got attention in designing humanoid robots to minimize firefighters' injuries and deaths as well as increase productivity, safety, efficiency, and quality of the task given. The types of robots used in different categories are telerobots, telepresence robots, mobile robots, autonomous robots, and android robots. Compared with telerobots, telepresence robots provide feedback from video, sound, and other data, and so it is widely used in fields requiring monitoring, such as in child nursery and education, and in improving older adults' social and daily activities. Mobile robots are designed. Autonomous robots, which can perform tasks independently and receive power from the environment, are created to mimic humans. Numerous types of vehicles for firefighting at home and extinguishing forest fires exist; still, there is a need for robots to be able to work on their own or be controlled remotely to extinguish the fire. In this paper, a cost-effective, compact-sized, unmanned support vehicle firefighting robot is proposed, which is designed and constructed to search and extinguish the fire in narrow spaces during critical situations.

8.1.1 Need for automatic fire extinguishing robot

During critical fire accidents in places like homes, industries, nuclear power plants, petroleum refineries, and gas tanks, people and properties exposed to higher risks are firefighters, humans in

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that building, and the occupied space. According to statistics from the National Interagency Fire Center, there were 59 k fire accidents and 10.1 million acres burned down in 2020 around the world, double the space burned compared with the previous year's data. During fire disasters, many humans lose their lives. As per the ADSI-2019 report, there were 11,037 fire accidents reported across India in 2019. Since these disasters are increasing day by day, a cost-effective fire extinguishing robot has become obligatory in all such places. It is a challenging task to design fire extinguishing robots for hazardous situations, considering the size, material, and technology involved. The robot has to be equipped with sensors to detect the fire and remove obstacles from the path while searching for the fire. After locating the source of the fire, the robot should be able to extinguish the fire. Also, it should have the facility to allow the remote user to monitor, operate, and control the robot through a wireless communication system. Additionally, it has to face the hindrance of entering narrow and restricted places to extinguish the fire. To rescue buildings and objects from getting destroyed, compact-sized robots are required. Technological innovations can be used efficiently to facilitate highly responsive firefighting tasks. This work involves the development of a firefighting robot to avoid unnecessary dangers.

8.1.2 Existing methods

Swetha Sampath [1] proposed a robot that turns on automatically when it detects a fire within a distance of 5−10 cm using a thermocouple. The robot was experimented at a temperature of 300°C, which tried to extinguish the fire by moving in the direction of fire intensity. This technology does not support current technologies of monitoring and controlling from a remote place. Teh Nam Khoon et al. [2] developed an autonomous firefighting mobile platform and showed it to be a feasible project. Based on the findings, by integrating all the hardware, such as flame sensors, motor driver circuitry, and light-dependent resistor (LDR) sensors, the expected patrolling and fire extinguishing tasks can be carried out and executed with a minimum level of error. Additional features can be integrated into the system, namely the wireless communication module so that it can communicate between the operator and the victims within the fire site. Mangayarkarasi [3] proposes a system that uses an RF remote for remote operation along with RF receiver-based microcontroller circuit for operating the robot and water pump. This project can be developed by interfacing it with a wireless camera so that the person can view the controlling operation of the robot from a remote display. Alif et al. [4], QRob is designed to be more compact in size than other conventional firefighting robots to ease small location entry for deeper reach in extinguishing fire in a narrow space. QRob is also equipped with two sensors, an ultrasonic sensor to prevent it from hitting any obstacle and surrounding objects and a flame sensor for fire detection. The sensors enable QRob to identify fire locations automatically and to extinguish the fire remotely from a certain distance. QRob is programmed to find the fire location and stop at a maximum distance of 40 cm from the fire. A human operator can monitor the robot by using a camera connected to a smartphone or remote device. However, QRob does not have a backup system for more water supply. Garu et al. [5] designed a robot that can extinguish the fire before it rages out of control with minimum human intervention. The main objective was to build a framework to identify and quench the fire before the fire expands and creates any hazardous situation.

8.1.3 Scope and objective

Fire causes huge damage and loss to human life and property. It is sometimes impossible for firefighters to access the place of fire because of explosive materials, smoke, and high temperature. It is observed that robots can be more reliable for this job where human lives are at risk. Robots can be used to reach the environment in a short time, which is beyond human access. In such environments, autopilot fire extinguishing robots (AFER) can be useful in extinguishing a fire. Fire extinguisher robots are designed to be used in such extreme conditions. It can be operated and controlled by remote users with the ability to extinguish a fire after locating the source of the fire. Fire extinguisher robots are provided with a monitoring system and work on wireless communication technology. The fire detection system is designed using the sensors mounted on the fire extinguisher robot. Environmental fire is detected by the flame sensor, and sensed signals are transmitted to the microcontroller to trigger the pump, which sprinkles water to extinguish the fire. This robot is controlled using a mobile phone through a Bluetooth module. The information on flame, temperature, smoke, and presence of obstacles in the place of accident is detected by the sensors and processed by the Arduino Uno board; the processed information is then activated by the robot.

8.1.4 Literature survey

The evolution of robots from its start till the present day has been surveyed [6–10]. Craig's *Introduction to Robotics* [6] explains the history of industrial automation characterized by periods of rapid changes in popular methods. As a cause or, perhaps, as an effect, such a series of changes in automation techniques seem closely tied to world economics. The use of these unique devices, along with different design techniques such as computer-aided design (CAD) systems and computer-aided manufacturing (CAM) systems, characterizes the latest trends in the automation of the manufacturing process, saving time and human errors. The paper on the *Evolution of Robotics Research* [7] provides an overview of the evolution of research topics in robotics from classical motion control for industrial robots to modern intelligent control techniques. The introduction of industrial robots led to robotics research that has evolved toward the development of robotic systems to assist humans in dangerous, risky, or hazardous chores. With more and more complexities with these events, flexibility has been demanded in industrial robots, and robotics research has been led toward an adaptive and intelligent system that helps replace humans. In *Real-Time Obstacle Avoidance for Manipulators and Mobile Robots* [8], Khatib points out it is necessary to take care of obstacles that lie in the way or track of a moving object or vehicle. Khatib's paper presents an approach for manipulators and mobile robots based on the artificial potential field concept to achieve obstacle avoidance. They have described the formulation and implementation of this approach based on the artificial potential field concept. Since collision avoidance is generally treated as high-level planning, it has been demonstrated to be an effective component of low-level real-time control in this approach. Thus, they have briefly presented their operational space formulation of manipulator control that provides the basis for this obstacle avoidance approach and have described a two-level architecture designed to increase the real-time performance of the control system. The papers on *Robot Introduction in Human Work and Environment* and *Design and Implementation of Common Platform for Small Humanoid Robots* [9,10] suggest understanding common safety problems with robot installation in human working environments. We have seen robots used in applications to offer economic advantages, increased productivity, and higher consistency. With this kind of automation, manipulation of robots in the human environment would be risky as it may lead to technical failure. Hence they suggest sharing components and introducing standard frameworks to provide safety and progress in general. Also, these papers suggest having a common platform for all humanoid robots being used for research to avoid inefficient methodology.

The evolution and history of cyber-physical systems have been explained in different works [11–15]. *Cyber-Physical Systems—Concept, Challenges and Research Areas* [11] describes the nature and importance of cyber physical systems (CPSs), which play a major role in the design and development of future engineering systems where controlling of mechanical systems is done using computing paradigms, which also includes areas such as generic architecture, design principles, modeling, dependability, and implementation. These systems have developed to represent the integration of information and knowledge into physical objects. The main aim of these systems is to develop CPSs that are event-driven multiagent models that can combine the physical and cyber components and facilitate the correct study of their interdependencies. In *Cyber-Physical Systems: A Confluence of Cutting-Edge Technological Streams* and *Cyber-Physical Systems: A New Frontier* [12,13], the authors have worked in close coordination with the physical components and computational entities as a closed-loop control system through networked communications, which emerges as a great potential application. The above said work describes the characteristics, state-of-the-art research, challenges, and opportunities for solving complex application-level problems in CPS. The authors illustrate the concept of CPS with an example problem of tracking a bio-chemical weapon being carried by a terrorist. Wireless communication might encounter inaccurate measurements; CPS makes use of inaccurate or incomplete data from sensor networks to make intelligent control decisions to operate the actuators for effective control of physical processes. Sha et al. [13] discuss optimization, data transmission, and network security in wireless communication systems to show that the prospect of CPSs is prominent. In the *Security Aspects of Cyber Physical Systems* and *Cyber-Physical System Security and Impact Analysis* [14,15], the authors have discussed security threats imposed on CPSs by attackers to spoil them.

Security threats are of two types—control security and information security. Based on this division, various attack methods and their possible solutions have been discussed here. Illustrations are done by considering a smart home, consisting of several sensors, actuators, and cyber controllers, as all these devices are connected to a cyber system via the Internet or local net. As these devices share a lot of data over a server on the net, security concerns are raised regarding personal life involving personal information.

The paper on *The Role of Edge Computing in Internet of Things* [16] signifies the use of edge servers or edge computing to process data on the edge of the network as many IoT devices rely on computing paradigms for improving productivity and revenues. It also facilitates processing delay-sensitive and bandwidth-hungry applications near the data source. The paper by Liu et al. [17] is a work on blockchain-based video streaming systems that help in building decentralized networks with flexible monetization mechanisms for video streaming services. Video transcoding, which is computationally intensive and time-consuming, is still a major challenge on these blockchain-based platforms. Hence this paper proposes a novel blockchain-based framework with an adaptive block size for video streaming with mobile edge computing. Surveys [18,19] suggest that several new computing applications, such as virtual reality and smart environments, have become possible due to the availability of cloud resources and services. The cloud computing paradigm is unable to meet the requirements of low latency, location awareness, and mobility support. Therefore mobile edge computing (MEC) was introduced to bring cloud services and resources closer to the user by leveraging available resources in the edge networks so that the applications can process the data with greater accuracy and efficiency. The article on *Edge Computing in IoT-Based Manufacturing* [20] proposes an architecture of edge computing for IoT-based manufacturing. It also analyzes the role of edge computing from four aspects, including edge equipment, network communication, information fusion, and cooperative mechanism with cloud computing. This article aims to provide a technical reference for the deployment of edge computing in the smart factory as well as a system architecture for implementing edge computing in IIoT applications. Edge computing in IIoT meets real-time requirements of lightweight intelligent manufacturing, increasing the agility and security of the network. Edge computing provides obvious advantages in terms of business agility and bandwidth optimization compared with traditional approaches.

Kristi et al. [21] developed intelligent firefighting tank robots, consisting of compass sensors, flame detectors, thermal array sensors, white detectors (IR and phototransistors), sound activation circuits, and micro switch sensors to sense and extinguish the fire. The main objective of the robots is to search a certain area, and find and extinguish the flame for different flame positions. Singh et al. [22] developed an autonomous industrial firefighting mobile robot. They described the construction and design of mobile firefighting robots, containing isolated direct current (DC) motors, water pumps, and water containers to perform the task. The robots perform analog to digital conversion of the data provided by five infrared sensors, out of which two sensors control the motion of the robots, and three of them are for flame detection. The objective is to make the robots sense the flames of the fire, making use of the infrared sensor as an input sensor that helps in sensing the infrared rays coming out of the fire and the ability to extinguish it in that particular area of occurrence.

A wireless firefighting robot developed by Swathi Deshmukh [23] has the ability to detect fire and extinguish it using light-dependent resistors. The light-dependent resistors are used for the detection of fire, and the resistors are highly sensitive devices capable of detecting even a very small fire. This robot is developed with the concern of security at home, buildings, factories, and laboratories and is an intelligent multisensory-based security system that also contains a firefighting system.

A cell phone-controlled robot developed by Lakshay Arora [24] consists of fire detection sensors and a mobile phone to control a robot by making a call to the mobile phone connected to the robot. Whenever the call gets activated, the tone corresponding to the mobile phone attached performs actions accordingly. This particular system uses a dual-tone multiple-frequency (DTMF) technology, which is used to position the motor shaft at the required point with different sensors, each performing its own task. Arpit Sharma [25] developed an android-phone-controlled robot using Bluetooth. The aim is to capture gestures using an accelerometer and Bluetooth module to control the kinetic motion of the robot. Signals from the sources are controlled by a microcontroller, which helps in performing actions for the defined inputs.

Saravanan [26] has designed and developed an integrated semiautonomous firefighting mobile robot, which is controlled autonomously by a navigation system comprising infrared and ultrasonic sensors as well as a wireless camera to capture the videos and transmit them to the base station.

With the help of graphical user interface (GUI) support the robot can be controlled from the base station. LDR and temperature sensors are used to detect the fire. An intelligent fire extinguisher system is developed by Sonsale et al. [27], and their paper proposes an adaptive fusion algorithm for fire detection. This robot makes use of the smoke sensor, flame sensor, and temperature sensor for fire detection. It also contains an intelligent multisensory-based security system that helps in the detection of abnormal and hazardous situations occurring at places and notify them. Being an intelligent system, it cuts off the electricity of the area where fire has been caught and starts sprinkling water only in that area.

A remote-controlled firefighting robot developed by Phyo Wai Aung [28] describes the functions of the robot that contains a transmitter and a receiver in which two sets of RF (radio-frequency) modules are used. One of the modules is used to transmit the data to the motor driver, and the other is used to know the condition of the fire. The motors connected to the microcontroller are driven by L298 and ULN2003 drivers in this system. Robot movements are controlled by using a wireless camera mounted on the robot. If the temperature of the fire sight is above 40°C, the alarm starts ringing so that the operator can control the firefighting robot and avoid the damage of heat. In *Fire Fighting Robot Controlled Using Android Application* [29] the robot is remotely controlled using an android application. It makes use of two sensors to detect the fire – the smoke sensor (light intensity) and temperature sensor. It also makes use of commands, such as moving forward, left, and right, sent to the robot by using an android device. At the receiving end, two motors are interfaced to the microcontroller, one for the movement of the robot and the other to position the arm of the robot.

Fire Fighting Robot: An Approach [30] suggests the development of fully autonomous robots and implements the concepts of environmental sensing and awareness and proportional motor control. It uses an microcontroller manufacturer product number (SMCL) microcontroller to process information from its various sensors and hardware elements. It also makes use of ultraviolet, infrared, and visible light to detect various components of its environment.

Although a lot of research has been done in the field, the requirement for a fire extinguisher robot with technological advancements still exists. In this chapter, an intelligent AFER is proposed and developed. It is equipped with four different sensors, which help the robot to detect fire at longer ranges and is 60% more accurate than other robots. A flame sensor is used to sense environmental fire and feed the signals to the microcontroller to trigger the pump to sprinkle water to extinguish the fire. The robot is designed to have wheels with large belts so that it can move easily on any terrain. It has a water backup system, which other robots do not have. The robot is controlled manually or by using a mobile phone through Bluetooth. It has a 360-degree rotating robotic arm, which other robots do not have. The robot processes information from its various key hardware elements, such as the flame sensor, temperature sensor, smoke sensor, and ultrasonic sensor, via Arduino Uno board.

8.2 Proposed system: materials and methodology

The proposed system is classified into mechanical schematics, hardware description, and programming design. All these parts were assembled, and experiments were performed to determine the optimal distance of the proposed robot to extinguish the fire.

8.2.1 Block diagram

The rough sketch of the proposed robot is shown in Fig. 8.1. Based on the requirements, hardware components and technologies were combined, as shown in Fig. 8.2. Google SketchUp software and AutoCad were used to construct 3D and 2D schematic diagrams. The proposed robot has two wheels on the rear side and two wheels on the front side to obtain the chosen movement and speed to frame the main structure of the robot. For the wheels to stabilize the robot and make rotations, 360-degree rotation is used. The body of the robot is made of a heat-resistive acrylic plate to protect the electronic circuit. The acrylic sheet is resistant to the heat of up to 200°C. The body of the acrylic chassis contains holes that make it easier for the mounting of various types of sensors and other mechanical components. An ultrasonic sensor is installed in the front of the robot to avoid hitting obstacles. The flame sensor is used to detect fire. A mini camera installed on the front side of the robot is linked to a smartphone to monitor the location.

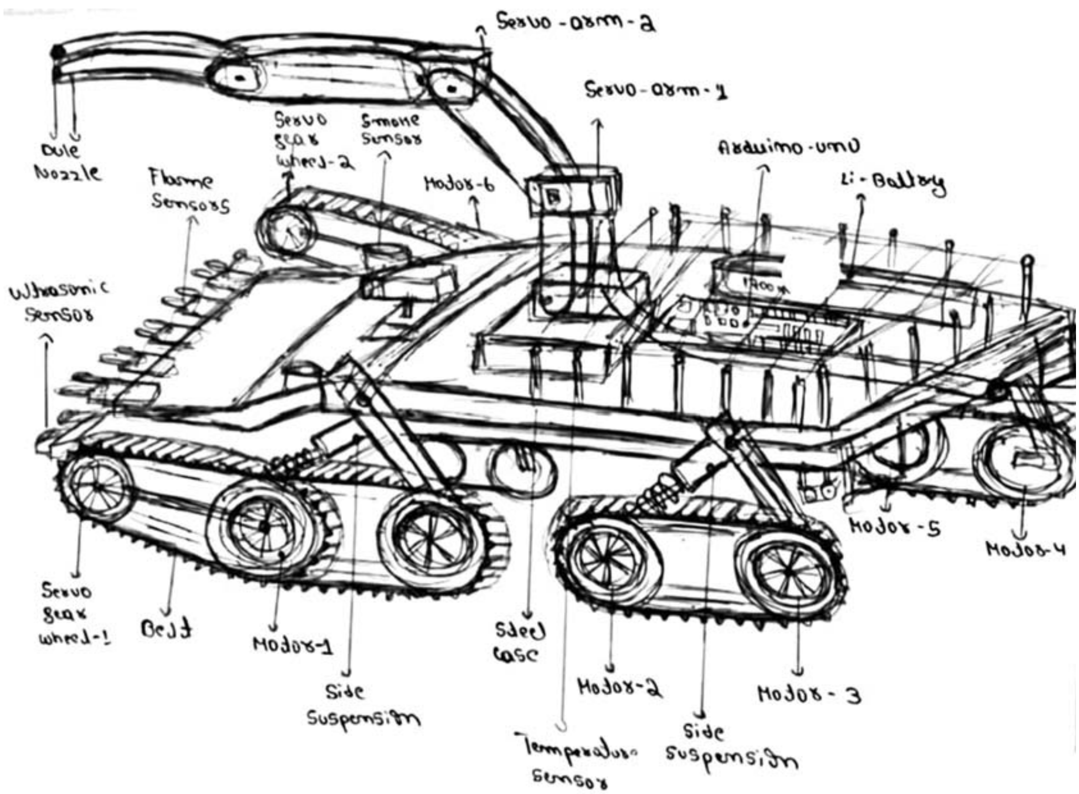

FIGURE 8.1

Rough sketch of the robot.

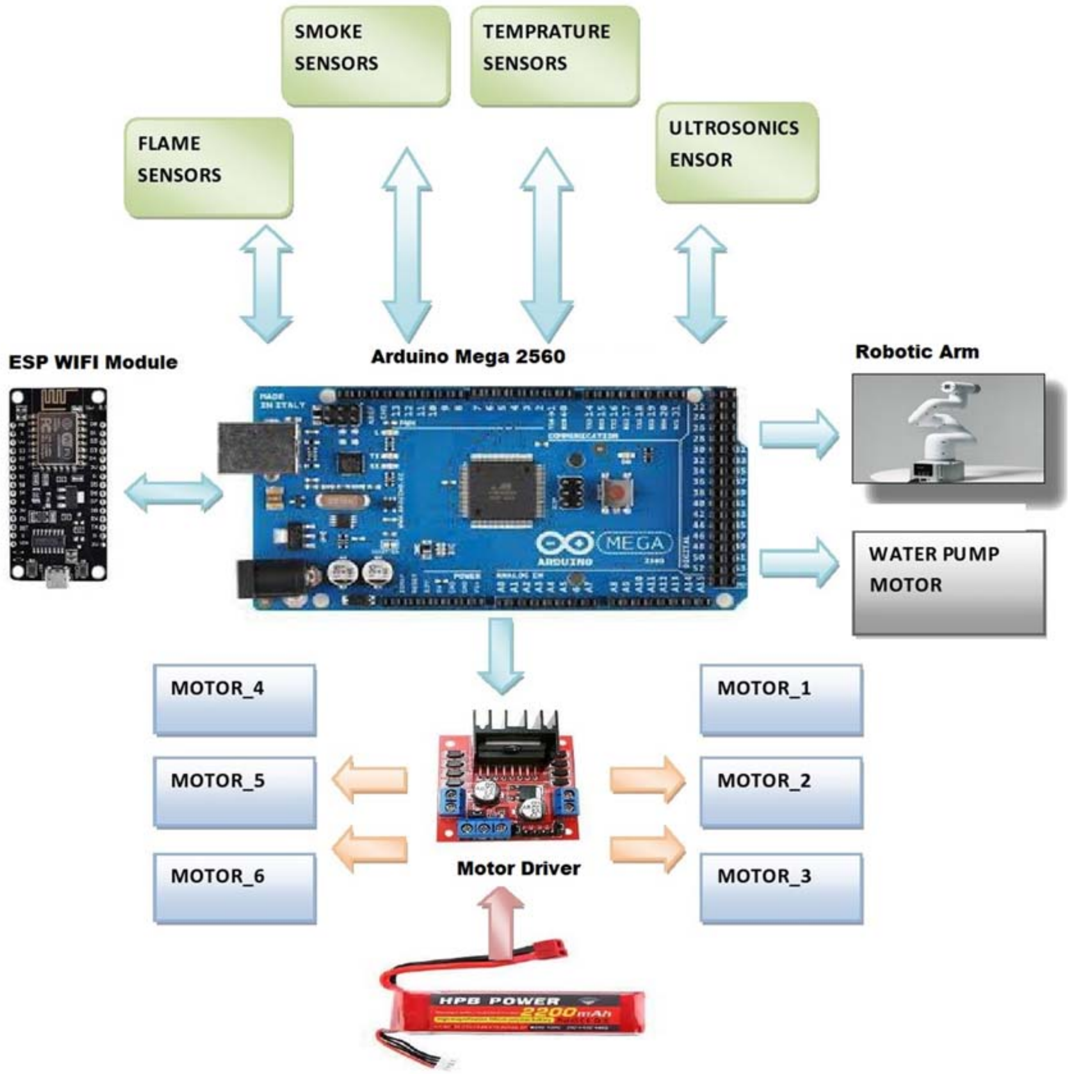

FIGURE 8.2

Block diagram of the proposed robot.

8.2.2 Required software

The Arduino project provides an integrated development environment (IDE) based on the programming language *Processing*, which also supports C and C++. The open-source Arduino IDE makes it easy to write the code and upload it to the board. Embedded C is a generic term for a programming language written in C, associated with a particular hardware architecture. Embedded C is an extension to the C language with additional header files, which change from controller to controller. Embedded C programming requires nonstandard extensions to the C language to support features such as fixed-point arithmetic, multiple distinct memory banks, and input/output operations. Arduino board designs use a variety of boards and controllers. The boards are equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards or breadboards (for prototyping) and other circuits.

8.2.3 Arduino software

It is an easy-to-use hardware and software, which is primarily an open-source electronics platform used for many purposes. It can use different sets of inputs like a finger on a button, light on any sensor, etc. The Arduino project provides an IDE based on Processing language. The Arduino IDE supports C and C++ using special rules of code structuring. A text editor for writing codes, messages, text consoles, toolbars with different buttons for functions and a series of menus all form part of the IDE. Arduino uses the concept of a sketchbook – a standard place to store programs; the first-time use of Arduino software will automatically create a directory for the sketchbook. Each processor is, in turn, somehow connected to embedded software, which decides and is responsible for the functioning of the embedded system. Microcontrollers are most significantly programmed using embedded C language. The two most important features of embedded programming are code speed and code size. Processing power and timing constraints determine the code speed and program memory available, and which programming language is used determines the code size in the embedded system. The aim of embedded system programming is maximum features in minimum space and time. It has several advantages like low power consumption, rugged operating ranges, and low per unit cost. These systems are based on a microcontroller. Embedded C programming requires nonstandard extensions to the C language to support features such as fixed-point arithmetic, multiple distinct memory banks, and input/output operations. Embedded C is a generic term for a programming language written in C, associated with a particular hardware architecture. Embedded C is an extension to the C language with additional header files.

8.3 Implementation

This module can work both as an access point and as a station; hence it can easily transmit data to the Internet making IoT as easy as possible. It also fetches data using application programming interfaces (APIs), helping devices or systems access any information on the Internet. The programming of this module is done using Arduino IDE, which makes its features more exciting. Some applications include smart home applications, wireless data logging, portable electronics, etc. A fire extinguisher robot with a robotic arm has three sections: Obstacle detection; temperature, flame, and gas sensor detection; robot direction control. The flowchart of the proposed work is given in Fig. 8.3.

8.3.1 Obstacle detection

The block diagram, flow chart, and schematic diagram of obstacle detection are shown in Fig. 8.4, in which an ultrasonic sensor senses the obstacle and sends a signal to Arduino, which generates the command for the robotic arm to clear the path.

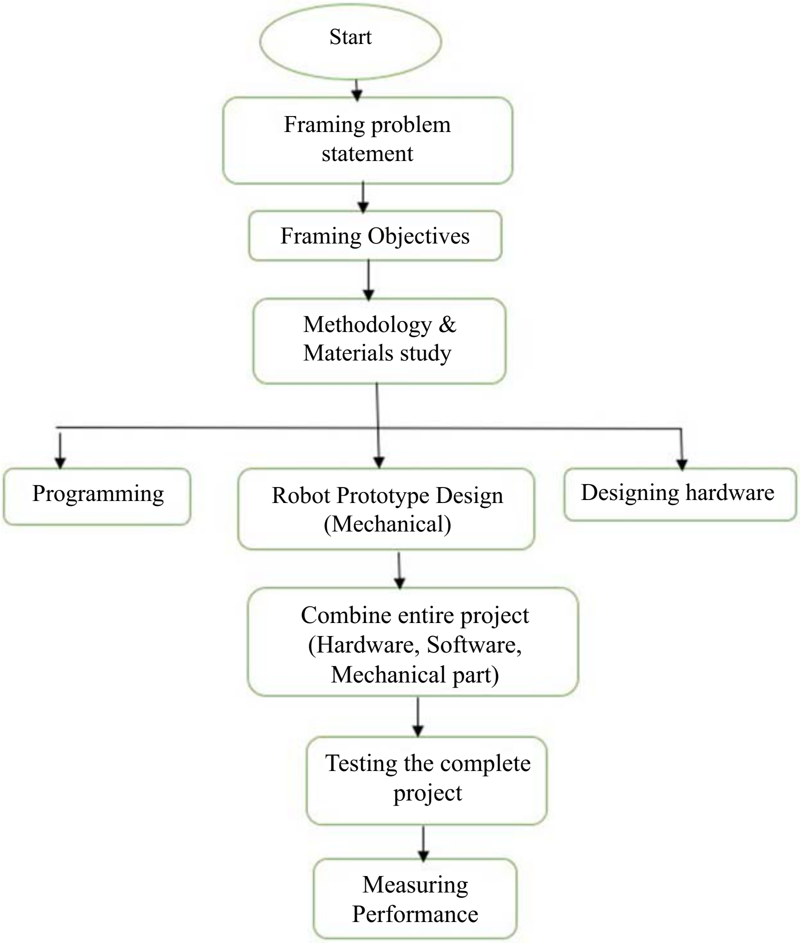

FIGURE 8.3

Flowchart of the proposed work.

8.3.2 Temperature, flame, and gas sensor detection

The block diagram and flow chart of flame, gas, and temperature sensors are shown in Fig. 8.5, in which the temperature sensor detects the temperature of the environment, and if the temperature crosses its limits, it activates the flame sensor to sense the fire. The flame sensor sends the signal to Arduino, after which Arduino generates the command for the water sprinkler to put the fire off from the desired location.

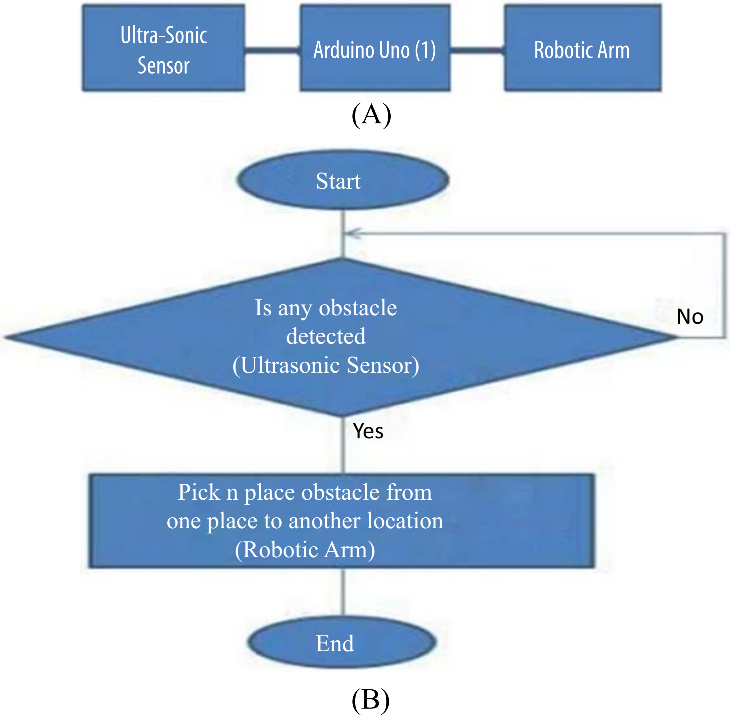

FIGURE 8.4

Flowchart of (A) obstacle detection section (B) functional flow.

8.3.3 Robot direction control

The block diagrams of video feedbacking and robot movement are shown in Fig. 8.6, in which an android cell phone is connected to the laptop via a mobile internet protocol (IP) camera application connected with its IP address of the desired location. Furthermore, the RF remote control controls the robot's direction — the robotic car can be moved in any direction.

8.3.4 Components involved

The hardware part is one of the imperative components in the development of the proposed robot, which includes several types of sensors, microcontrollers, DC motors with wheels, transmitters and remote controls, and water pumps. Fig. 8.2 shows the block diagram of the proposed robot. The diagram shows that various information like flame, smoke, temperature, and obstacle objects in and around the fire accident zone is sensed by the flame sensor, smoke sensor, temperature sensor, and

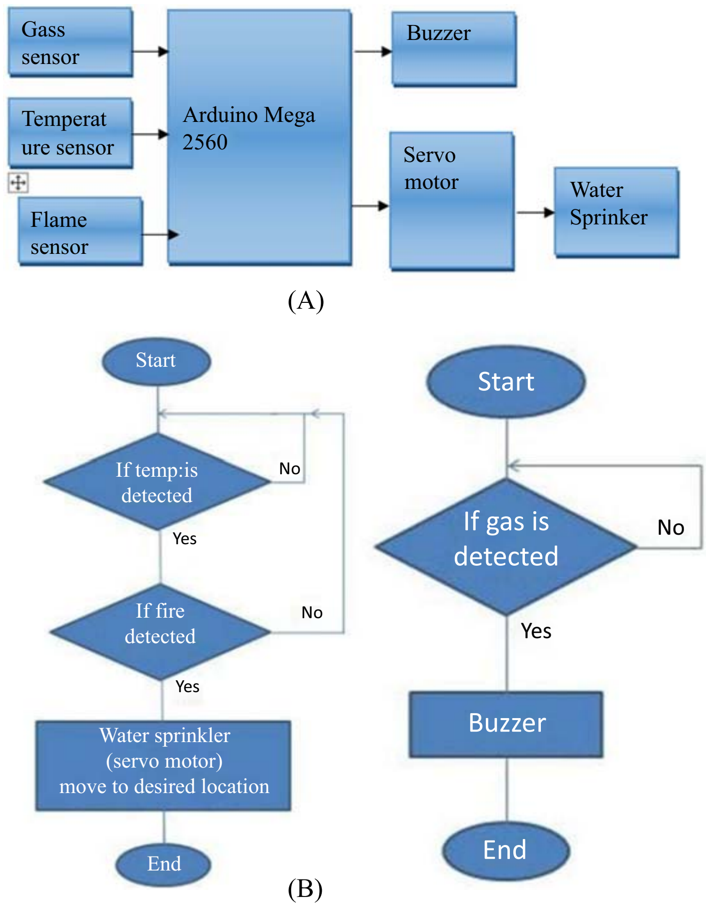

FIGURE 8.5

Flow chart of (A) flame, gas, and temperature sensors (B) functional flow.

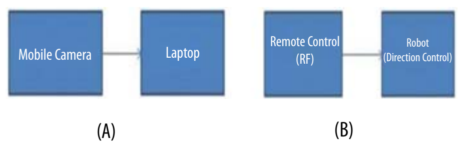

FIGURE 8.6

Flow chart of (A) video feedbacking (B) robot movement.

ultrasonic sensor, respectively. The sensed signals are sent as inputs to Arduino Uno, which processes the received signals to produce controlling signals for the appropriate devices. All hardware components are connected to Arduino Uno. To activate the moving of the gear motor, the motor driver (L298N) is connected to the central unit, while the transmitter remote control will provide the output of the system. The remote operator can control the flow of water and the fire extinguisher pump. On the other hand, the robot's movements can be monitored by the remote operator using a camera connected to a smartphone. The required components for implementing this project are listed in Fig. 8.7.

8.3.4.1 Flame sensor

The flame sensor, which identifies the origin of the fire first, plays an imperative role in most firefighting robots and acts as an eye for a robot. It has two signal pins—digital output (DO) and analog output (AO). The DO pin gives two information – there is flame or no flame, while the AO pin detects the exact wavelength of different lights. When the wavelength of light is at 760–1100 nm, the robot can identify fire effortlessly. The detection angle is roughly 60 degrees, and the distance is 20 cm (4.8 V) to 100 cm (1 V).

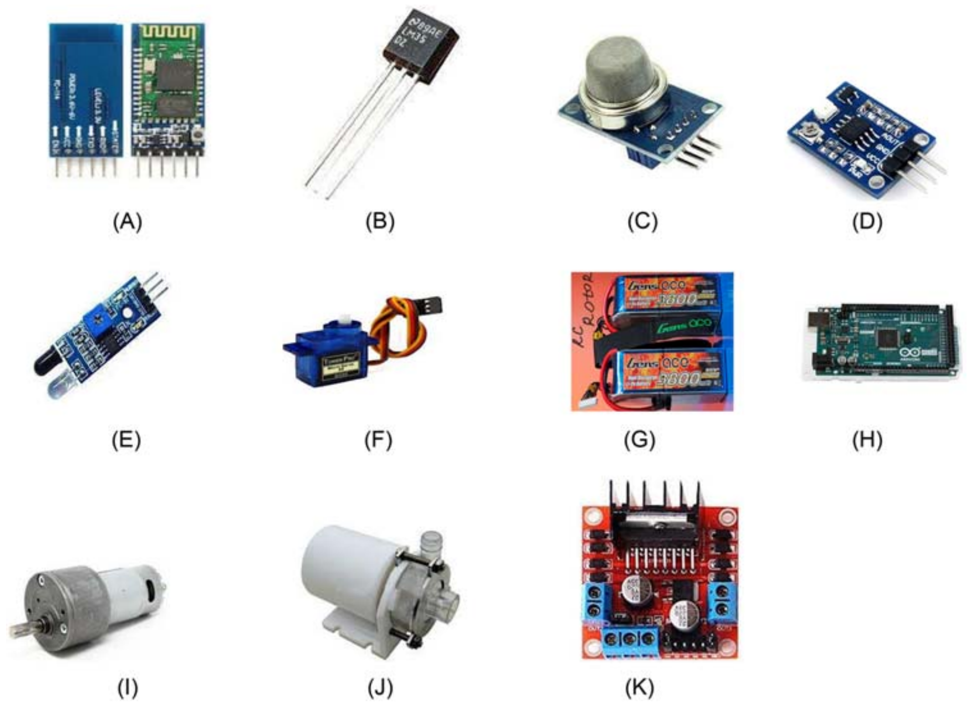

FIGURE 8.7

Required components (A) Bluetooth module (HC-05), (B) temperature sensor (C) smoke sensor (D) ultrasonic sensor (E) infrared sensor (F) servomotor (G) lithium polymer battery (H) ATmega2560 microcontroller (Arduino Uno) (I) geared motor (J) water pump (K) motor driver.

8.3.4.2 Ultrasonic sensor

The main hindrance to the automatic detection of fire is obstacles on the path while searching the fire. The obstacle has to be removed from the path to improve the performance of AFER. The sensor must be simple, compact, low cost to produce accurate sensing data values and be functional on a larger scale. Moreover, it should be smart to sense obstacles with enough boundaries to enable robots to respond and move in the appropriate direction. The existing sensors that suit all these requirements are ultrasonic sensors. The HCSR04 ultrasonic sensor is used in this study to detect obstacles within the range of 2–10 cm. However, it rotates at an angle of 360 degrees after a particular range is detected. This sensor transmits electromagnetic waves and receives reflected waves from the object to measure the location of the object. It has four output pins such as a reference voltage (Voltage Collector Collector (Regulated DC supply voltage (VCC))) (which operates around 5 V), ground pin (GND), digital output (DO), and analog output (AO).

8.3.4.3 Temperature sensor

The temperature sensor is a device to measure the temperature through an electrical signal, which requires a thermocouple or RTD (resistance temperature detectors). If the difference in voltage is amplified, the analog signal is generated by the device, which is directly proportional to the temperature. It is available in the dimensions of $224 \times 120 \times 60 + 40$ mm and can detect temperature in the range up to 100°C.

8.3.4.4 Smoke sensor

MQ2 gas sensor is an electronic sensor used for sensing the concentration of gases in the air, such as liquefied petroleum gas (LPG), propane, methane, hydrogen, alcohol, smoke, and carbon monoxide. MQ2 gas sensor is also known as a semiresistor. This sensor works on 5 V DC voltage and can measure concentrations of flammable gas of 300–10,000 ppm.

8.3.4.5 Servomotor

A servomotor is an electrical device that can push or rotate an object with great precision. The servomotor is used when the robot wants to rotate its robotic arms at a specific angle or distance. It is made up of a simple motor that runs through a servo mechanism. It has an average speed of 60 degrees in 0.16 seconds, a weight of 62.41 g, and a size $40.7 \times 19.7 \times 42.9$ ($L \times W \times H$) in mm.

8.3.4.6 Lithium polymer battery

Instead of a liquid battery, a lithium technology based rechargeable polymer electrolyte battery called lithium battery or lithium-ion polymer battery is used in this work (abbreviated as LiPo, LIP, Li-poly, lithium-poly). The electrolyte is formed by using a semisolid of high conductivity. These batteries provide higher specific energy than other types of lithium batteries. Due to its light weight, it is used in applications such as mobile devices, radio-controlled aircraft, and electric vehicles.

8.3.4.7 ATmega2560 microcontroller (Arduino Uno)

The ATmega2560 microcontroller (Arduino UNO) board is the brain of the robot containing the navigating and firefighting program. This microprocessor was chosen due to its speed and versatility to be used within almost any project. The versatility allows the different sensors to be controlled by one microprocessor. The processor has three analog-to-digital converter (ADC) ports, two of which have the capability of running up to 16 different channels. This would allow us to use all the analog sensors we had planned and have room for extra if needed.

8.3.4.8 DC gearmotor with wheels

A gearmotor is a specific type of electrical motor designed to produce high torque while maintaining a low horsepower, or low speed, motor output. The working voltage for a DC motor is around 5−10 V DC, while the ratio of the gear is 48:1. Suitable current for this motor is 73.2 mA. A DC motor is used to move the robot to the fire location. It has a speed of 100 rpm at 12 V and is available in the length of 46 mm and weight of 100 g. Johnson Electric provides gearmotor drive solutions to the automotive industry worldwide, including micro motors, gearboxes, and electronic interfaces.

8.3.4.9 Water pump

The water pump is an important component of this robot as it has to pump water to extinguish the fire depending on the class of the fire that occurs. The water pump selected for use in this project is small in size and lightweight. It has low noise, high effectiveness, and minimal power consumption. The optimal voltage for this water pump is 6 V, and the working voltage is around 4−12 V with a working current of 0.8 A.

8.3.4.10 Motor driver

The L298 motor driver is a high voltage, high current dual full-bridge driver designed to accept standard TTL (transistor-transistor logic) levels and drive inductive loads such as relays, solenoids, DC, and stepping motors. Two enable inputs are provided to enable or disable the device independently of the input signals. The motor driver has a dimension of 43 × 43 × 26 mm with a weight of 26 g.

8.3.4.11 HC-05 bluetooth module

HC-05 has a red light emitting diode (LED), which indicates the connection status with the Bluetooth. Before connecting to the HC-05 module the red LED blinks continuously in a periodic manner. When it gets connected to any other Bluetooth device, its blinking slows down to two seconds. This module works on 3.3 V. We can connect 5 V supply voltage as well since the module has a 5−3.3 V regulator on the board. As HC-05 Bluetooth module has a 3.3 V level for receiving/transmitting (RX/TX), and the microcontroller can detect a 3.3 V level. There is no need of shifting the transmit level of the HC-05 module, but we need to shift the transmit voltage level from the microcontroller to the RX of the HC-05 module. The HC05 Bluetooth module is a universal asynchronous receiver/transmitter (UART)-serial converter module and can easily transfer the UART data through wireless Bluetooth. The Bluetooth module has a frequency of 2.4 GHz industrial, scientific, and medical (ISM) band and PIO (programmed input/output) control and comes with an integrated antenna and edge connector. The HC-05 Bluetooth module can be used in master or slave configuration.

8.4 Experimental results and discussion

The robot is aimed to detect obstacles, temperature, and smoke/flame to perform the operations resulting in the extinguishing of the fire effectively and efficiently. The design prototype of our proposed AFER is shown in Fig. 8.8.

8.4.1 Obstacle detection

As a primary objective, there must be a clear path or a direction in which the robot will move, as there should not be any obstacle restricting its movement toward the direction of the fire. So, the robot makes use of the ultrasonic sensor placed above the device, helping in detecting and making its arm operate over the obstacles and making way for the device to continue further. The robotic arm opens up the gripper. The process of obstacle detection – picking and placing the obstacle toward the left side for path clearing is shown in Fig. 8.9.

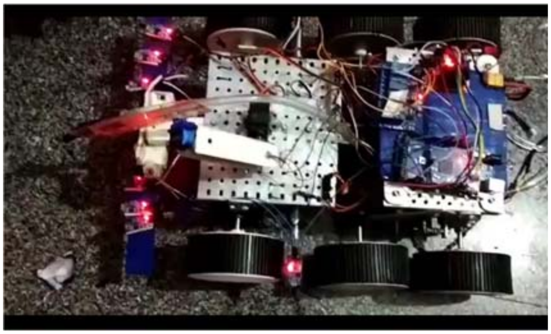

FIGURE 8.8

AFER compact prototype.

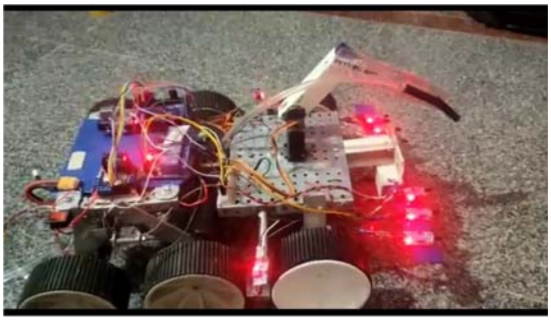

FIGURE 8.9

Detecting the obstacle and robotic arm moving toward the obstacle and opening the gripper.

8.4.2 Temperature, flame, and gas sensor detection

Similarly, after clearing its way to the destination, the next task is to detect or sense the temperature, smoke, or flame to operate its arm for sprinkling water in the direction of the fire. It makes use of the temperature sensor when it is capable of finding out the area or premises that are on fire as that would raise or increase the temperature at that particular area. The flame sensor finds out the places affected by the fire, and the robot then moves in that direction, activating the servomotor and the water pump that helps sprinkle water in that direction. The gas sensor helps in the detection of the concentration of toxic or flammable gases, which also helps the robot to judge the areas that are affected and to move in that direction. After the robot detects the fire, it extinguishes it with the water sprinkler. Fig. 8.10 shows AFER with the backup for more water supply.

Fig. 8.11 shows temperature sensor detection. Once the fire is extinguished, the robot automatically changes its direction. If no smoke, temperature, and fire is detected, then the robot goes to sleep mode. It gets switched on if the temperature sensor detects any temperature.

8.4.3 Performance measures

The performance of the proposed AFER depends on the performance of the sensor. The speed and accuracy of the AFER depend on the sensors. The input and the expected and actual output are tabulated in Table 8.1 for the flame sensor, Table 8.2 for the ultrasonic sensor, Table 8.3 for the smoke sensor, and Table 8.4 for the servomotor. It is observed from Table 8.1 that the flame sensor detects fire when a piece of paper is put up with a fire. The flame sensor is expected to detect flames in the 760−1100 nm wavelength range. The sensor is particularly sensitive to the flame spectrum. The sensor has a detection angle of 60 degrees and detects fire within the range of 100 cm with an accuracy of 95%.

It is observed from Table 8.2 that the ultrasonic sensor detects an obstacle in the path of the robot by sending electromagnetic waves in the range of 300 kHz with a maximum distance of 30 cm. However, it rotates 360 degrees after a particular range is detected with an accuracy of 95%.

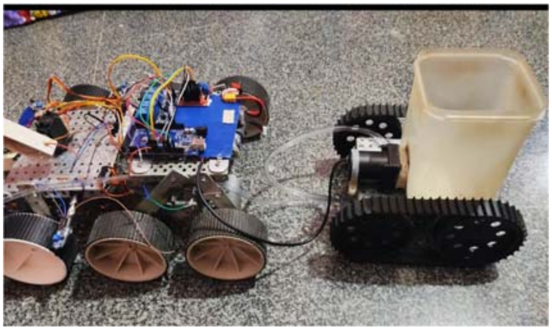

FIGURE 8.10

AFER with backup for more water supply.

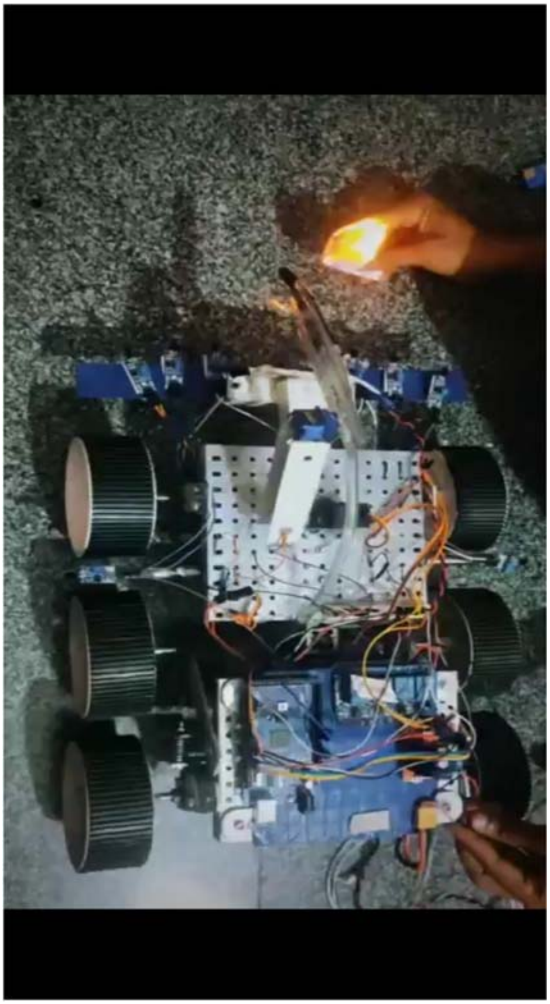

FIGURE 8.11

AFER detecting fire.

Table 8.1 Performance measures for flame detection (using a flame sensor).

Parameters	Flame detection performance
Sample input	Place a piece of burning paper
Expected output	Can detect flames in the 760−1100 nm wavelength range; detection angle is 60 degrees.
Actual output range	0.8 m or approximately 100 cm
Accuracy	Around 95%

Table 8.2 Performance measures for obstacle detection (using an ultrasonic sensor).

Parameters	Obstacle detection performance
Sample input	Place an obstacle in the direction of the robot
Expected output	Maximum of 30 cm at 300 kHz with resolution as low as 1 mm
Actual output range	8–10 cm with 360-degree rotation after detection
Accuracy	Around 95%

Table 8.3 Performance measures for smoke sensor (using a smoke detector).

Parameters	Smoke detection performance
Sample input	Burn a piece of paper to generate smoke
Expected output	Smoke detectors can be installed up to 41 ft. high and 10 ft. wide.
Actual output range	Detects gases in the concentration range of 200–10,000 ppm

Table 8.4 Performance measures for rotation of robotic arm (using servomotor).

Parameters	Robotic Arm performance
Power	5 V
Average speed	60 degrees in 0.16 s
Max. Torque	21.48 N-m
Max. Speed	3000 rpm
Max. Current	24.81 A

It is observed from Table 8.3 that the robot detects smoke when a piece of paper is burnt to generate smoke. It detects gases in the concentration range of 200–10,000 ppm.

It is observed from Table 8.4 that the robotic arm should be moved at a greater speed to remove obstacles from the path. The robotic arm is connected to a servomotor with a maximum speed of 3000 rpm. The average speed of servomotor is found to be 0.16 seconds.

8.5 Conclusion

This work proposes an intelligent and compact AFER is proposed to provide a technical solution to save firefighters from danger. The robot can evade obstacles, search for fire, and extinguish the fire. A device called NodeMCU (ESP8266) has been used in the project, which acts as an edge device to which all the sensors and motors are connected. The NodeMCU on the robot acts as a server that provides resources, data, and services as well as access to a Wi-Fi network from another device. The mobile or laptop through which the user can control the robot using a Wi-Fi network acts as the station. The information is sent by the station as a mode of client and server architecture. The remote user can control the movements of the robot through the information that is stored in the edge server. The designed robot is equipped with four different types of sensors to increase its capacity for handling different environments compared with QRob, which has two sensors. Temperature, flame, smoke, and ultrasonic sensors detect the corresponding parameters in the affected environment, which are processed by the controller. The body of the robot is made of a heat resistive acrylic plate to protect the electronic circuit in the robot. Its compact size enables it to enter narrow spaces. Once the location of the fire is identified, the robot stops at a certain distance (40 cm) from the fire and sends the signal to Arduino. Arduino generates the command for the water sprinkler to quench the fire from the desired location. A mini camera installed is linked to the smartphone to monitor the location. The robot has wheels covered with large belts so that it can operate easily on any terrain. It also has a water backup system, which other fire extinguishing robots do not have. There is both an automatic and manual control for the robot. The proposed robot has a 360-degree rotating robotic arm, which QRob does not have. The sensors of the proposed robot can detect for longer ranges and have more accuracy than QRob. With all these advanced features, the designed AFER is also cost-effective. The placing of the sensors, however, is a very challenging task. Future innovations in the field of robotics may allow us to communicate with a collection of robots to cooperate in a mission with the ability to receive instructions on-the-fly during an operation.

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