REPUBLIC OF TÜRKİYE

ALTINBAŞ UNIVERSITY

Institute of Graduate Studies

Electrical and Computer Engineering

DEVELOPMENT AND ANALYSIS OF RADIO CONTROLLED FIREFIGHTER ROBOT

Samah Khairullah Thabet THABET

Master's Thesis

Supervisor

Prof. Dr. Galip CANSEVER

Istanbul, 2023

DEVELOPMENT AND ANALYSIS OF RADIO CONTROLLED FIREFIGHTER ROBOT

Samah Khairullah Thabet THABET

Electrical and Computer Engineering

Master's Thesis

ALTINBAŞ UNIVERSITY

2023

The thesis titled DEVELOPMENT AND ANALYSIS OF RADIO CONTROLLED FIREFIGHTER ROBOT prepared by SAMAH KHAIRULLAH THABET THABET and submitted on 26/4/2023 has been **accepted unanimously** for the degree of Master of in Electrical and Computer Engineering

_____

Prof. Dr. GALİP CANSEVER

Supervisor

Thesis Defense Committee Members:

Prof. Dr. Galip CANSEVER	Departments of Engineering and Architecture, Altınbaş University	_____
Asst. Prof. Dr. Sefer KURNAZ	Departments of Engineering and Architecture, Altınbaş University	_____
Ass. Prof. Dr. Yuksel BAL	Departments of Engineering Computer Engineering, Topkapi University	_____

I hereby declare that this thesis meets all format and submission requirements for a Master's thesis.

Submission date of the thesis to Institute of Graduate Studies: ___/___/___

I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Samah Khairullah Thabet THABET

Signature

DEDICATION

I dedicate this thesis to my beloved husband, whose love and support has been my constant source of strength and inspiration. Thank you for always believing in me and encouraging me to pursue my dreams.

ABSTRACT

DEVELOPMENT AND ANALYSIS OF RADIO CONTROLLED FIREFIGHTER ROBOT

THABET .,Samah Khairullah Thabet

M.Sc, Electrical and Computer Engineering, Altınbaş University

Supervisor: Prof. Dr. Galip CANSEVER

Date: April / 2023

Pages: 59

Firefighting operation is perilous because firefighters face dangerous situations while extinguishing fires and rescuing victims. The aim of this study is to design and develop a robot that assists firefighters in extinguishing a fire. A robot was manufactured that is able to go to the middle of the fire and extinguish it, and the behavior of the fire is monitored by means of the camera in the robot. This robot makes it possible to extinguish the fire in a shorter time before it spreads, and thus leads to reducing material losses that increase with the expansion of the fire. To build a fire rescue robot Arduino program was used to monitor and control its operation. A fire detection system using infrared sensors and temperature sensors was used, a fire extinguishing system using a water tank and a pump, and the vehicle was equipped with a remote monitoring camera. In addition, the robot is not autonomous in its movement and is controlled remotely using the (FLYSKY FS-i6) radio device. The firefighting vehicle is designed with the aim of assisting firefighters in fighting fire and is therefore an essential tool to reduce fire risks.

Keywords: Fire, Arduino, Robot Firefighting, FLYSKY FS-I6, Flame Sensor, Temperature Sensor.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

NFPA   :   National Fire Protection Association

USFA   :   US Fire Administration

OSHA   :   Occupational Safety and Health

1. INTRODUCTION

1.1 INTRODUCTION

Every year, several people are killed and property is destroyed in fires. Based on the statistics of the National Fire Protection Association (NFPA, 2013), an estimated 1,389,500 fires were recorded in 2011. As a result of the flames, 3,005 civilians were killed, 17,500 civilians were wounded, and over $11 million in direct property damage was caused. That implies that every 208 minutes, a civilian died as a consequence of a fire, and every 30 minutes, a civilian was injured[1][2].

Statistics show that firefighters account for the highest proportion of deaths in the United States, according to another report from the US Fire Administration (USFA), which states that 82.9 firefighters have died each year on average over the last ten years, resulting in approximately $13 billion in property damage[3].

Firefighters are placed in dangerous situations when putting out flames and rescuing victims. A career in firefighting is one of the most physically and emotionally taxing jobs in the world, with over 80,000 injuries reported annually (NFPA, 2014). Training is essential for firefighters since experience and knowledge levels are inversely related to their risk of being sick or injured at work.[4].

Researchers considered various ways to reduce the number of deaths and ownership loss. One useful way is to swiftly a powerful firefighting robot on the fire scene. A firefighting robot is an autonomous or remote-controlled machine designed to assist firefighters in combating fires. These robots can help in a variety of ways, such as detecting and extinguishing fires, providing situational awareness to firefighters, and performing tasks that are too dangerous or difficult for human firefighters. The robot can enter the fire scene quickly and put out the fire without taking the time to set up complex planning details because it is not affected by issues like smoke and a lack of oxygen, whereas firefighters without robots should take the time to set up extinguishing planning details for their own safety. As a consequence, the robot not only replaces firemen but also reduces the likelihood of life-threatening circumstances and property damage[5].

Overall, firefighting robots are becoming increasingly important in the fight against fires, as they can assist human firefighters in dangerous and challenging situations.

The primary goal of developing a firefighting vehicle that can assist in dealing with numerous fire accidents in homes and small-scale companies. Many home goods catch fire when people are sleeping or gone, which can lead to a variety of hazardous situations if the fire is not extinguished quickly.

1.2 PROBLEM STATEMENT

Firefighters have received training in accordance with Occupational Safety and Health Administration (OSHA) regulations and training recommendations (OSHA, 1985). According to OSHA guidelines, when firefighters arrive at the fire scene, they shall create a team to set up the extinguishing planning elements such as danger monitoring, buddy system, and so on. The firefighting robot, on the other hand, can enter a fire scene fast and extinguish it without spending time setting up sophisticated planning elements. As a result, firefighting robots lessen the requirement for firemen in potentially hazardous circumstances. When robots replace or assist firemen on missions, the difficulties that firefighters face is decreased, and robotic technology allows for the rescue of many more victims. Despite the robot's remarkable benefits, there are hurdles that must be overcome for optimal functioning [6].

The goal of this discuss is to create and construct an intelligent firefighter robot capable of extinguishing fires. The robot will be designed and built to travel into the center of a fire and extinguish it while also sending photographs from the event location using a camera to expand understanding about fire behavior.

1.3 RESEARCH QUESTIONS

The questions of the study are:

a. What knowledge and innovations could be helpful to increase the mobility and fire-extinguishing capabilities of firefighting robots?

b. How can the effectiveness of a fire-fighting robot be assessed and confirmed?

1.4 OBJECTIVES

This dissertation has three excellent research objectives:

i. To design and develop a sophisticated robot fire fighter that can navigate through a hazardous environment, detect and extinguish fires, and communicate with human firefighters.

ii. To evaluate the performance of the robot fire fighter in simulated fire scenarios and compare its performance with existing robotic systems.

iii. To identify the limitations and challenges associated with the development and deployment of robot fire fighters and propose solutions to overcome them.

1.5 PROJECT SCOPE

i. This research focuses will develop and analyze remote control firefighting robot.

ii. In this paper, locally available fire and water resistant materials will be used to design a firefighting robot to navigate in a hazardous environment, detect and extinguish fires, and communicate with human firefighters.

iii. The Arduino microcontroller will be used as the conversion unit of the robot.

iv. The limitations and challenges associated with the development and deployment of robot firefighting will be identified, and solutions will be proposed to overcome them.

1.6 THESIS OUTLINE

This project is divided into five chapters, which are briefly discussed below:

Chapter 1: Explains an introduction to the study of the construction and development of a firefighting robot, including an explanation of the problem, research questions, objectives, and scope of the project.

Chapter 2: provides an overview of robots and also a firefighting robot. As well as a literature evaluation for the firefighting robot, which includes the study's goal, robot components, and application.

Chapter 3: This chapter explains the framework for achieving the desired goals. The component used to build the robot and its user-controlled mechanism are shown.

Chapter 4: It includes a real test of the robot in a fire environment to ensure the success of the extinguishing process.

Chapter5: include the summary of the study (conclusion) and the future work.

2. LITERATURE REVIEW

2.1 INTRODUCTION

As technology has been developed, capabilities of machines or robots have diversified, and now it does not surprise people that robots take on most human tasks that are more suitable to robots than humans, increasing productivity and efficiency. For these reasons, the needs for robots to do various purposes and functionalities keep increasing.

Also, because of the increase of the needs for robots, more various robots have been developed and manufactured for use in daily life (e.g., robot vacuum, soccer robots, surgery robots, etc.).

This chapter will be divided into four main sections: a brief overview of robots and the fields in which they are applied, next an introduction to firefighting robots is presented and an explanation of why they are so needed in our lives, then an overview of firefighting robotic platforms and finally, past research related to the project will be highlighted.

2.2 A BRIEF OVERVIEW OF ROBOTS

Robots are complex machines that are designed to perform specific tasks, using a combination of mechanical, electrical, and computer systems. They can range in size from small machines that fit in your hand to large industrial robots that can be as tall as a building. A robot is defined as "a machine capable of carrying out a complex set of actions automatically, especially one programmable by a computer" by the Oxford English Dictionary. Robotics is a scientific, engineering, and technology multidisciplinary field concerned with the design, building, and use of mechanical robots [7].

Robots are generally programmed to perform tasks autonomously or under the control of a human operator. They can be pre-programmed to carry out certain tasks or built to gradually learn and adjust to new circumstances. They frequently have a variety of sensors, including cameras, microphones, and touch sensors, which enable them to observe their surroundings and engage with them in different ways [8].

Robots can be categorized based on their operating environment Figure (2.1). Fixed and mobile robots are the most prevalent distinctions. Because these two types of robots function in quite different contexts, they require extremely distinct characteristics.

Typically, fixed robots are industrial robotic manipulators that work in clearly defined environments designed for robots. Industrial robots work in companies that produce automobiles, doing repetitive tasks like soldering or painting parts.

Robotic manipulators are being utilized increasingly often in less controlled contexts, such extremely precise surgery, as sensors and tools for human-robot interaction increase. Robots that can move around and do jobs in large, ill-defined, unexpected surroundings were called movable robots. These environments weren't made just for them. They have to cope with unforeseen situations that evolve over time. Unpredictable entities like people and animals may exist under such conditions. Mobile robots include things like self-driving automobiles and robotic vacuum cleaners.[9].
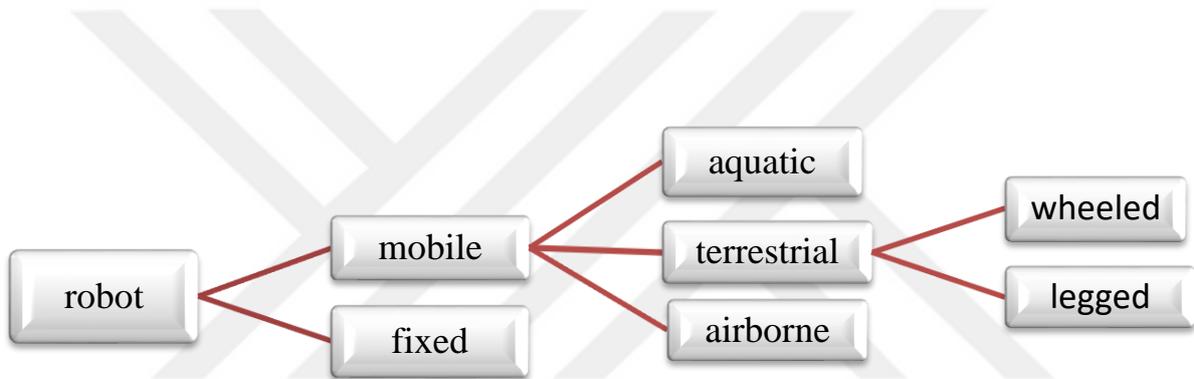
Figure 2.1: Robot Classification Based on Surrounding Interaction Mechanism

Robots are classified based on their intended application and the functions they perform, as shown in Figure (2.2). Industrial robots are machines that are used in manufacturing and production processes. Often, they are employed for repetitive jobs like welding, painting, and assembling. Robotic assistants help individuals with their tasks. They include domestic chores like vacuuming, modes of mobility like autonomous vehicles, and military uses like reconnaissance drones. The use of robots in surgery, physical therapy, and medical education is growing. [10].
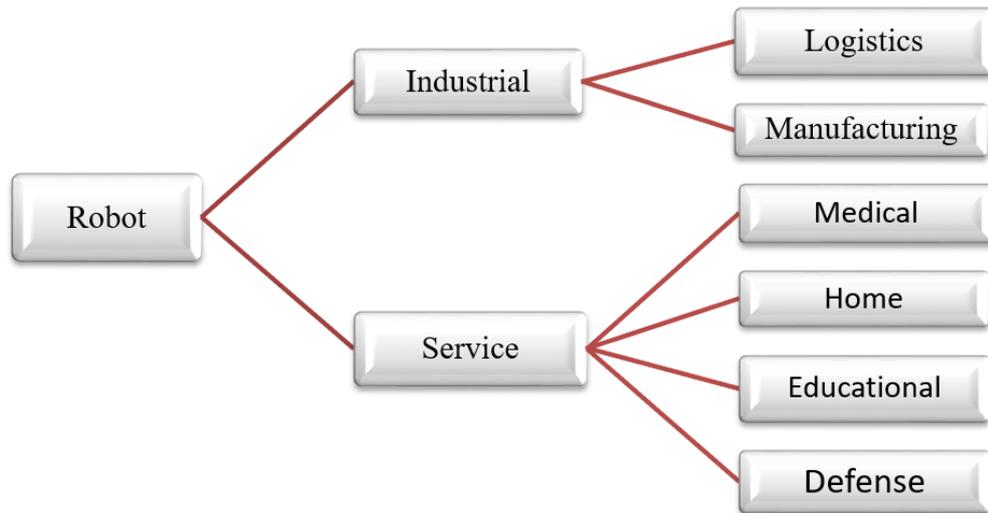
Figure 2.2: Displays Robot Classification According To Application.

2.3 FIREFIGHTING ROBOT

The need for robots or devices that can notice and extinguish fires on their own is long overdue. Fire accidents occur when someone is sleeping or not at home, or due to carelessness in laboratories, shops, etc. The invention of this device can minimize the loss of fire to people and property, thereby saving people and property to a greater extent in the worst-case scenario, fire causes significant financial and human losses. These robots are the finest approach to protecting humans, their environment, and their riches. It can actively navigate by itself and detect and extinguish fire [11]. This robot can be utilized as an emergency device in specific instances. It is constructed in such a way that it can detect a fire as soon as it starts and extinguish it before it spreads and causes significant damage. In the future, the firefighting robot will be able to collaborate with firemen, drastically reducing the risk of victim harm. It is an innovative endeavor in the realm of robotics that works toward rational and accessible access in order to save lives and prevent property damage [12].

2.4 FIREFIGHTING ROBOTIC PLATFORMS

Personal protective equipment such as gloves and facemasks are necessary when taking on the roles of firefighter, search and rescue member, or survivor. As a result, certain systems-such as firefighting, searching and rescue - may fail due to darkness, smoke, water power outages and noise. Additionally, standard mobile computers may malfunction due to the lack of working PPE equipment and/or gloves [13]. A smart firefighting and salvage system could theoretically facilitate dangerous intervention, data collection, storage, sharing, test, and integration from a range of dynamic databases and sensor networks for ecological observation. Each of the aforementioned domains comes with its own set of problems and obstacles.

The robots in Table (2.1) were developed to aid firemen or carry out firefighting via remote control and autonomous navigation.

Figure 2.3: Displays A Firefighting Robot Called LUF60.

LUF60 shown in Figure (2.3) is a well-known firefighting robot with an air or water-blasting monitor nozzle. It has an 800 GPM airflow and a range of 80 meters for water. Up to 400 degrees Fahrenheit, the rubber track system is heat resistant, enhancing mobility in challenging circumstances [14].

TAF 20, a powerful firefighting robot that can sweep away obstacles with bulldozer blades and extinguish flames with a powerful fan as in Figure (2.4). It can also blast water from a distance of 90 meters and spray water mist or foam from a distance of 60 meters. As the

robot can be controlled and operated remotely from up to 500 meters away, firefighters may send it into environments that could be hazardous [15].

Figure 2.4: TAF 20, Remotely Firefighting Robot.

The FIREMOTE outlined in Figure (2.5) is prepared with a fire-fighting spout, high-pressure water hardware, splash spout, route cameras, warm imaging camera that permit the administrator to screen the fire circumstance, cooling framework, and roll-flat hose channel. Because of the metal body that surrounds the device, the heat might be reflected away from you. By pumping water through the chassis and cooling the body with a fixed nozzle, the Chassis Wiper may shield the tracks and delicate components. The robot can maintain a reasonable body temperature while doing activities in hot environments [16].

Figure 2.5: FIREMOTE Ground Fire Extinguishing Robot.

The Snake Fighter AnnaKonda that was depicted in Figure (2.6) can move with the assistance of obstacles and extinguish fire using a spout that is attached to the front of the robot and is driven by water through the joint actuation. It can thrust against obstacles that are outside of level ground. In high temperatures, water is employed in conjunction with hydraulic joint actuation, fire extinguishment, and robot cooling. All of the robots listed above were built to perform outside firefighting activities because the bulk of contemporary firefighting robots need a person to remotely control their movements and are too large to be deployed indoors. The usage of the remote control has the crucial benefit of enabling the user to see the activity and make judgments from a safe location. [17][18].

Figure 2.6: The Snake Fighter Anna Konda.

Table 2.1: Contains Comparison of Robotic Fire Fighting Robots by Key Features.

Robot	Type	Operating Region	Perception	Operating Mode	Country of Origin
LUF60	Ground vehicle	Outdoor	Visual camera	Remote control	Germany
TAF20	Ground vehicle	Outdoor	N.A	Remote control	Germany
FIREMOTE	Ground vehicle	Outdoor	Visual camera	Remote control	United Kingdom
ArchiBot.M	Ground vehicle	Indoor	Visual camera	Remote control	South Korea
Anna Konda	Snake-like robot	Indoor/ Outdoor	Thermometer Visual camera	Autonomous	Norway
SAFFIR	Humanoid robot	Indoor	Thermal IR stereo/ Visual Camera	Autonomous	United States
HOYAROBOT	Mobile robot	Indoor	Thermometer	Autonomous	South Korea
FINE	Mobile robot	Indoor	Infrared Thermometer	Autonomous	Undisclosed

The autonomous firefighting robots listed below are well-known. The ArchiBot-M firefighting robot illustrated in Figure (2.7) is a mobile robot utilized in inaccessible areas for humans. It is utilized for on-site inspection and clearing the way for the fireman. For stair climbing and functioning at high temperatures, the robot was outfitted with a specifically built independent suspension system. The robot is also built to be water-resistant and fitted with a cooling system, allowing it to function in hot environments [19].

Figure 2.7: ArchiBot-M Mobile Firefighting Robot.

SAFFIR, a humanoid firefighting robot illustrated in Figure (2.8), is a parallel actuated biped with bio-inspired geometry capable of omnidirectional walking, balancing in sea state conditions, overcoming obstacles, and controlling fire suppressors [20].

Figure 2.8: SAFFIR , a Firefighting Robot At Sea.

The other is HOYAROBOT, a mobile firefighting evacuation guiding robot that can be controlled remotely, is designed to be dropped into high-risk regions, and provides the operator with environmental data. Moreover, by using voice communications between the firemen and the victims themselves, HOYAROBOT can find the victims and help with evacuation [21].

Another is FINE, which uses two proximity sensors to avoid obstacles and two infrared thermometers to detect fire. The original purpose of this robot was to extinguish small house fires [22].

2.5 RELATED WORK

Today, the fast advancement of science and technology allows for the use of new technological techniques and fire extinguishing measures in the extinguishment of flames of various complexity. Among the many advances in the field of firefighting, fire robots must be distinguished as a distinct item [23]. Fire robots are technological tools that can tell the difference between fire and smoke. A fire robot is a sophisticated technical device used to fight fires. Depending on mobility, there are stationary and mobile robots. Firefighting robots are used where people cannot get close to a fire because it is an immediate danger to their health and existence. Many industrial facilities may utilize fire-fighting robots to substantially simplify their job, and there are situations when even fire-fighting robots are indispensable, such as when radioactive and chemically dangerous things are on fire. There are situations where fires cannot be extinguished by traditional means: difficult for firefighters to reach, places where traditional sprinkler systems cannot be used. All this requires a new method of fire suppression [24].

Robots, both remote-controlled and autonomous, are deployed to extinguish the fires. The remote control has the significant benefit of allowing an operator to watch the event and make judgments from a safe location while using a wireless communication system [25]. Another significant benefit of remote controlled firefighting robots is the incorporation of human intelligence into robotic functionalities.

Furthermore, there are certain restrictions. First, one operator operating one robot at a time is preferable. When an operator controls several robots simultaneously, the operator could neglect to do the proper actions for each robot in a timely manner [16]. Second, operator must rely solely on the bare minimum of data supplied by the robot in a given situation. Third, restrictions in existing wireless communication technologies might result in intermittent connections, making data collecting and transmission difficult. Whereas autonomous robots are equipped with a system of avoidance of obstacles integrated into their autonomous navigation system [23]. According to the finding that s of this study [26],

developed and produced a semi-autonomous Fire Fighting robot for use in fire emergencies. Computer software for the three-dimensional solid modeling of a rescue robot was employed. Two DC electric actuators power the semi-autonomous robot. It travels on the ground using a tracking system made of sprockets and chains. To minimize heat-related damage, the robot was wrapped with ceramic fiber paper, which has very poor thermal conductivity. Aside from the mechanical construction of the fireproof fire rescue robot, two electrical circuits are fitted to regulate actuators and the extinguisher's solenoid valve. Also, the operator uses two remote controls with different frequencies to remotely control the robot's movement. A study by [27], outlines the creation of autonomous industrial firefighting robots (FFMR). The study outlines the building and design of a mobility firefighting robot. The technology makes use of two D.C. motors that are optically separated. The robot transforms the analog data generated by infrared sensors into digital information. Five infrared sensors are in use. Three sensors detect fires, while two control how the robots move. A water tank and a DC water pump make up the fire extinguisher. The identification and extinguishing of fires is the major focus of study. A fire's infrared rays are detected by this infrared sensor, which is employed as an entry sensor. The fire suppression system is managed by a microcontroller.

Another study [28], showed that an autonomous fire brigade robot has been created. This is a system that independently detects fires and extinguishes them with water jets. The fire model has been merged with a modular design based on proximity, vision, and infrared sensors. Water is sprayed by the robot from the manipulator to douse the flames. The program includes algorithms for integrated tracking, obstacle avoidance, flame detection, and motion. As an experimental module fire robot, it was constructed and tested in a simulated setting. Furthermore, research [29] developed a robot capable of locating and extinguishing fires in a specific environment. The robot navigates the circle, avoiding all obstacles on the way. The system has flame sensors for fire detection, infrared and ultrasonic sensors for navigation, and fans for battling fires. Live feeds and map displays are also provided so that humans can see the fire suppression path, not just robots, in case something unusual happens.

In the other hand, a robot created by [23] that could automatically put out a fire is also included. This work incorporates mechanical, electrical and ultrasonic systems. Automatic sensors incorporated into the robot's design gave it an ultrasonic range. This robot uses

three ultrasonic sensors to map its surroundings. By implementing an obstacle avoidance module, the analog data produced by these sensors is converted into digital form. This allows the robot to travel over a significant distance without getting stuck in between. When the flame sensor determines the center of the fire, the robot goes to the necessary distance and activates the fire extinguishing system. A candle is utilized as a source of fire for the test.

According to, [30] created and executed autonomous robot firefighting with the goal of assisting firefighters in a firefighting operation while also serving as an important instrument for operation risk reduction. To achieve the truck's autonomous capability, fire is detected using (Infrared (IR) and sensors of the temperature), and the fire putout system (tank, pump), and the navigation system (IR sensor, Direct Current (DC) motors) are implemented. The car also has a camera and a Wi-Fi module for sending live video feeds and sensor data to a server for remote monitoring.

Furthermore, [24] An autonomous fireman robot was developed, driven by an Arduino-based fire detection and extinguishing algorithm, and constructed of locally available fire- and water-resistant materials. The "Rashed tree" wood, sometimes referred to locally as "Kerosene wood," is used to construct the robot's frame. The water storage capacity is around one liter. An Arduino-based basic algorithm is used to detect fire and estimate the distance from the fire source as the robot approaches the fire to put it out. To put out a fire, use a centrifugal pump. This robot is useful because it can detect fire flames more effectively in low-light conditions.

Also, [11] has created a robotic truck capable of automatically detecting and fighting fires. Arduino can be used to detect and extinguish components such as gas sensors, relay drivers and their drivers, and motors. The robot is linked to a smartphone using a Bluetooth module, and an Arduino controller processes the analog and digital data from the sensors to determine whether there is a fire nearby. This project effectively reaches both hardware and software.

On the other hand, a robot has been developed by [31] for firefighting named QRob, which can suppress a fire without exposing firemen to undue danger. QRob is meant to be tiny to allow for more accessible entrance into small areas and a greater reach for extinguishing fires in tight spaces. In addition, QRob contains a flame sensor to detect fires and an ultrasonic sensor to prevent collisions with nearby objects and barriers. As a result, QRob

showed that it is capable of independently locating fire spots and putting out fires from a certain distance. QRob is programmed to find the fire and stop at a maximum of 40 centimeters from it. By using a camera that connects to a smartphone or other remote devices, a human operator may monitor the robot.

Many researches have been conducted to produce remote-controlled firefighting robots. For instance,[32] attempted to create a Fuzzy-based Microcontroller-controlled Robot. The only person who can traverse a model building, come upon a lit candle, and put it out with a Blower's help is the Robot. This is meant to mimic how a robot would actually operate if it were to combat fires in an oil field. To build an autonomous fire extinguisher robot that can identify and put out a fire on its own, a number of components must be put together. A thermostat sensor, modern DC motors, a water tank, a wireless remote, and a wireless camera are all included.

Another research, [12] presented and created a novel idea of indoor firefighting robot. It can traverse a variety of floor surfaces in buildings, including staircases. It can withstand temperatures as high as 700Co for about 1 o'clock while using a variety of thermal insulation techniques to keep the electrical components within at an appropriate temperature. It can climb stairs, make touch with people who are trapped or hurt, and give the control unit audio and video information about the fire situation within the building. It is geared to provide gas masks to those who are trapped.

Besides, [33] explained the functions of the remote-controlled firefighting robot. They have created a firefighting robot powered by the Internet of Things that can take the place of current firefighting robots. The system is composed of an Android APP and robot placed on the user's end, a MQ7 gas sensor connection, a fire sensor, an L293D motor driver, a water pump, and a CO2 pump. Additionally, CO2 sensor readings can be used to determine the nature of the fire, and observers can then manually signal a water or CO2 pump to use oxygen cylinders to extinguish the fire.

Furthermore, [34] has designed and constructed a fireproof fire rescue robot for fire extinguishment. The robot is developed and built to enter the heart of a fire, extinguish it, and broadcast photographs from the scene using a camera to expand knowledge of fire behavior. In this work, navigation, perception, and probabilistic real-time fire localization are presented independently. Enables the firefighting robots to categorize fire, smoke, and

thermal reflections by classifying their patterns, calculate safe heading to avoid static and dynamic barriers, and study local circumstances in uncharted settings using long-wave infrared camera pictures. Traveling in the direction of the fire and locating it even beyond the robot's field of view.

In addition, a dual-mode firefighting robot will be developed and implemented. The fire extinguisher robot may operate in both automated and manual modes. This test proposed by [35], demonstrates the planning, modeling, creation, and construction of a fire detection equipment that can spot flames immediately and put them out while employing a live surveillance camera to watch the fire accident site. The robot generally operates in automatic mode, but a remote control may be used to convert it to manual mode so that the fire can be extinguished manually. Because of its construction, the robot can defend itself by maintaining a safe distance from the fire. The processing and control system for the robot is an Arduino microcontroller. Proteus is used to simulate and analyze the robot model. The dual-mode robot's hardware has been created and tested. Furthermore, [36] designed and built a robot that can use a flame sensor to detect fire and can pump water into a designated fire area. Developed using IR flame sensor technology to produce a remote site firefighting robot. It features a remotely driven water pump for tossing water and a water tank. It was programmed using an Arduino UNO. This type can operate in automatic mode, but if a problem arises, it may be put into manual mode and the fire put out by using the remote control.

2.6 SUMMARY

This chapter covered studies on different types of robots, including firefighting robots. Next clarified studies of autonomous firefighting robots and robots that have the function of communication between them and humans, that is, they are controlled by the user by remote control. The chapter also discussed research related to the project

3. METHODOLOGY

3.1 INTRODUCTION

This chapter explains the procedure required to conduct this study, as shown in Figure (3-1). As it is shown the beginning with the previous studies that have been accompanied on research area in the open literature. In the next stage, bases on literature the present model has been modified. In order to achieve research objectives. After enhancing the present model, the model was assembled, then tested. Finally, the test results then analyzed to evaluate the proposed model. In the next section, modeling of firefighter robot is discussed.
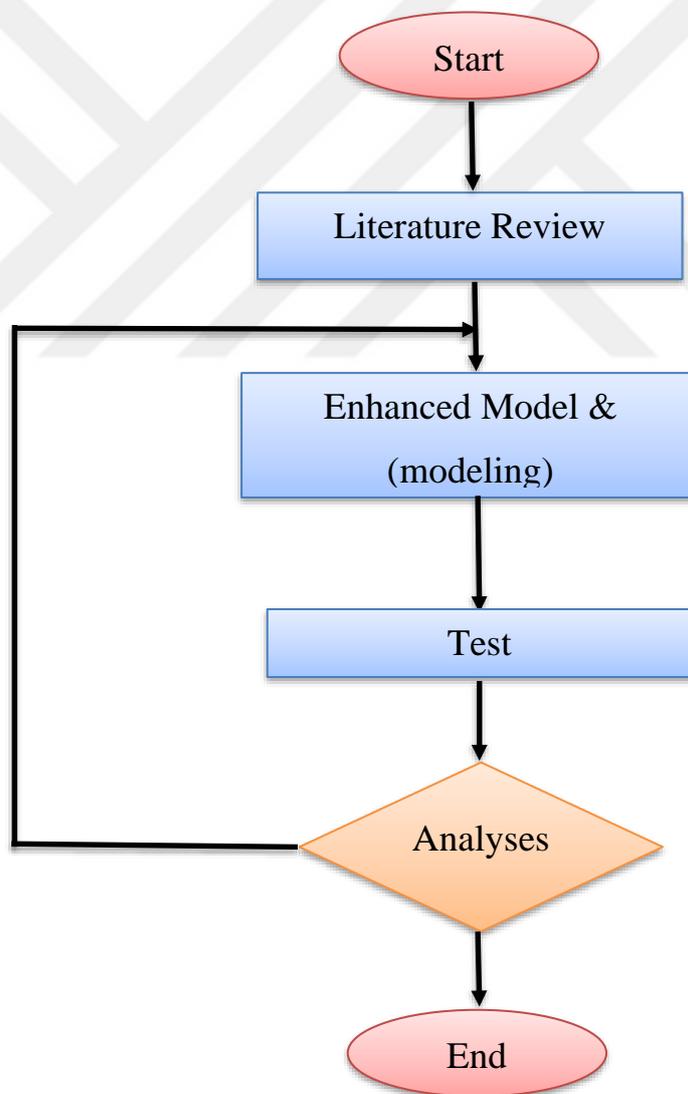
Figure 3.1: The Procedures Required For The Study.

3.2 MODELING OF FIREFIGHTER ROBOT

In this section, modeling of firefighter robot discussed. Starting with electrical part, body of robot as well as the theoretical part was discussed.

3.2.1 ELECTRICAL PARTS

3.2.1.1 CONTROL SYSTEM (ARDUINO)

The Arduino Mega board, which is based on the ATmega2560 microprocessor, is used for the robot's primary control. The board was chosen because it has a large number of digital I/O (input/output) pins and analog inputs that are simple to program using the Arduino IDE (Integrated Development Environment). It has a total of 54 input and output pins, of which 14 pins are used for PWM output, 4 for hardware ports, and 16 for analog inputs. One USB port, an ICSP header, a power jack, and one REST pin are also present on the board. Programmers can also benefit from hassle-free power supply alternatives and plug-and-play computer interface possibilities [37].

Figure 3.2: ARDUINO MEGA 2560 Microcontroller.

3.2.1.2 DC- MOTORS

Four DC motors are used operating voltage is 12V DC. Two of them are used to monitoring the movement of the robot, and two to control the movement of the water gun. Figure (3-3) show the DC-motor responsible for the movement of the robot & Figure (3.4) show the DC motor responsible for the water gun. It is connected to the microcontroller through the motor driver   (HY-DIV268N-5A).
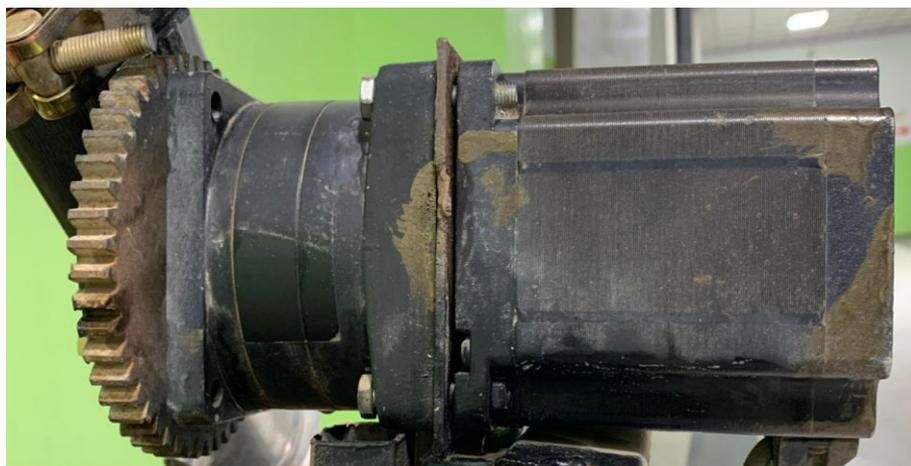

Figure 3.3: DC Motor for Robot Movement.

Figure 3.4: DC Motor For Robot Water Gun.

3.2.1.3 MOTOR DRIVER

The driver used was (HY-DIV268N-5A) shown in Figure (3.5), it is use to control the motor and connected with Arduion directly, because the control signals from the microcontroller do not contain enough electric current to spin the motor. The supply voltage of the stepper motor is 24V [38].
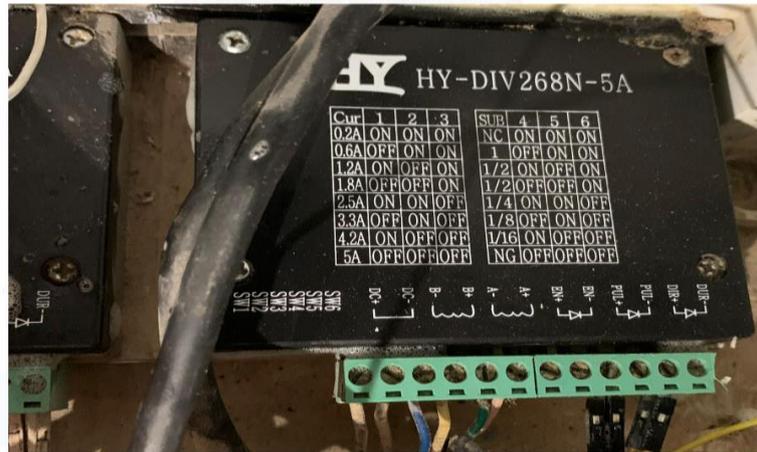
Figure 3.5: Motor Driver.

3.2.1.4 BATTERY

(Long 12v 7A) batteries were used for the purpose of increasing the number of working hours for the robot because it works with the battery charging system. It is effective for use at high temperatures in Figure (3.6).

Figure 3.6: Battery of the Robot.

3.2.1.5 RELAY

A relay is a switch that operates with electricity and its work is automatic, as it controls a high current circuit with a low voltage signal provided by the Arduino pins shown in Figure (3.7). The high voltage side has one conductor each with three jacks: common (COM), normally open (NO), normally closed (NC).

a. Common relay (COM): common pin.
b. Normally open relay (NO): The relay is always open, meaning that there is no connection between the circuits unless it receives a signal from Arduino to close the circuit.
c. Normally closed relay (NC): The relays are usually closed by default in the closed position, meaning that the circuits are in a state of communication unless they receive a signal from the Arduino to open the circuit.

Figure 3.7: Relay.

3.2.1.6 FPV GOGGLES

They are View goggles which give us a live transmission of the video being captured by camera. Shown in Figure (3.8), In order to ensure that the video reception will be uninterrupted and independent of the direction of travel, it is also possible to observe that

the FPV goggles include two separate receiver antennas, an omnidirectional and a directional one (transmitter antenna).[39]

Figure 3.8: FPV Goggles.

3.2.1.7 CAMERA

GSM Wi-Fi camera is used for live protest of the fired place where no human is available to provide services to stop the burning place shown in Figure (3.9).

We use this camera because we can control it remotely so that the camera itself can transmit a signal to the FPV Goggles device, which in turn gives us a live broadcast of the event site

The GSM camera has infrared LEDs for night vision and 24 hour monitoring.

Figure 3.9: Camera.

3.2.1.8 FLAME SENSOR

In many firefighting robots, sensors play an important role as they are always used to detect the center of the fire shown in Figure (3.10). The flame sensor is used to detect fire as it depends on the photo transistor (YG1006 NPN), which is a black object located at the front of the sensor where it is coated with black epoxy, which makes it sensitive to infrared radiation in the wavelength range of (760 to 1100) nanometer. The flame sensor has 4 pins which are Ground, VCC, analog output (AO) and digital output (DO). The analog output (AO) pins are used to discover the perfect wavelength of light while the digital output (DO) pins are used to indicate if there is a flame or no. [40].
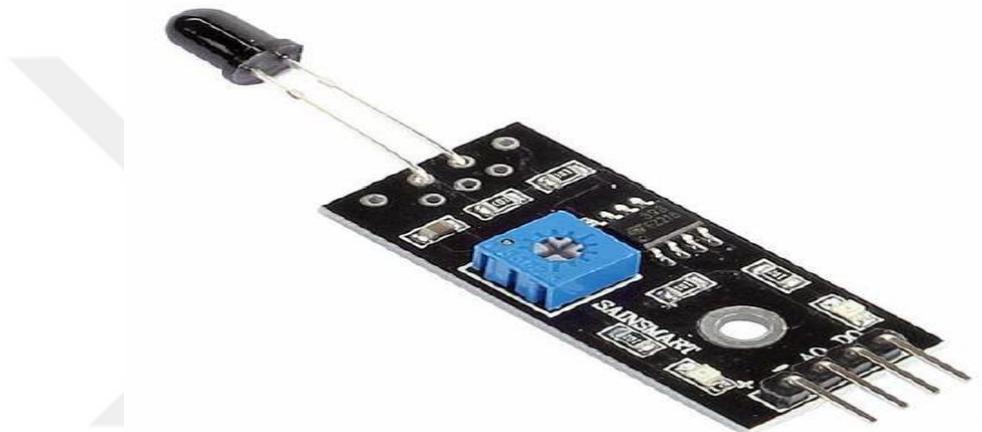

Figure3.10: Flame Sensor.

3.2.1.9 TEMPERATURE SENSOR

In Figure (3.11), The DS18B20 temperature sensor is a single wire digital temperature sensor, therefore in order to connect to the microcontroller, it just needs one digital pin and (GND). It works in a temperature range of -55 to 125 degrees Celsius.
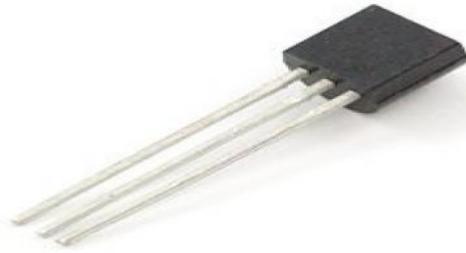
Figure 3.11: Temperature Sensor.

3.2.1.10 EXTERNAL CONTROLLER AND RECEIVER

It is a model (FLYSKY FS-i6) digital proportional radio control device operates in the global ISM band at a 2.4GHz frequency. The transmitter uses AFHDS 2A technology (Automatic Frequency Hopping Digital System 2nd Generation) to ensure reliable and interference-free communication between the transmitter and the receiver. This transmitter has the advantage that it doesn't required computer because it has a single LCD screen with a resolution of (128* 64) and can be set up simply using the buttons. The FS-iA6B receiver has a range of more than 500m and a reduced 6-channel collector. It also has a twin receiving antenna for excellent gathering, impedance, and dismissing abilities [41]. Figure (3.12) show the Transmitter (FLYSKY FS-i6), Figure (3.13) show the statuses of the transmitter (FLYSKY FS-i6), Figure (3.14) Transmitter's side & back view (FLYSKY FS-i6) &Figure (3.15) shows the receiver (FS-iA6B).

Figure 3.12: FLYSKY FS-i6.
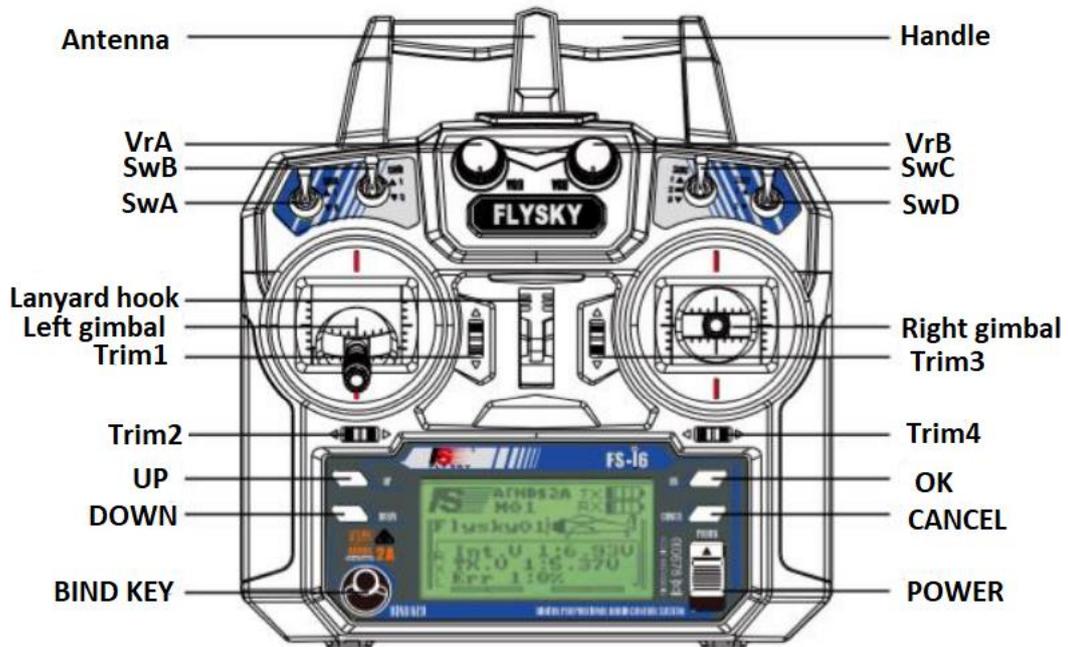
Figure 3.13: Show The Statuses Of The Transmitter (FLYSKY FS-i6).
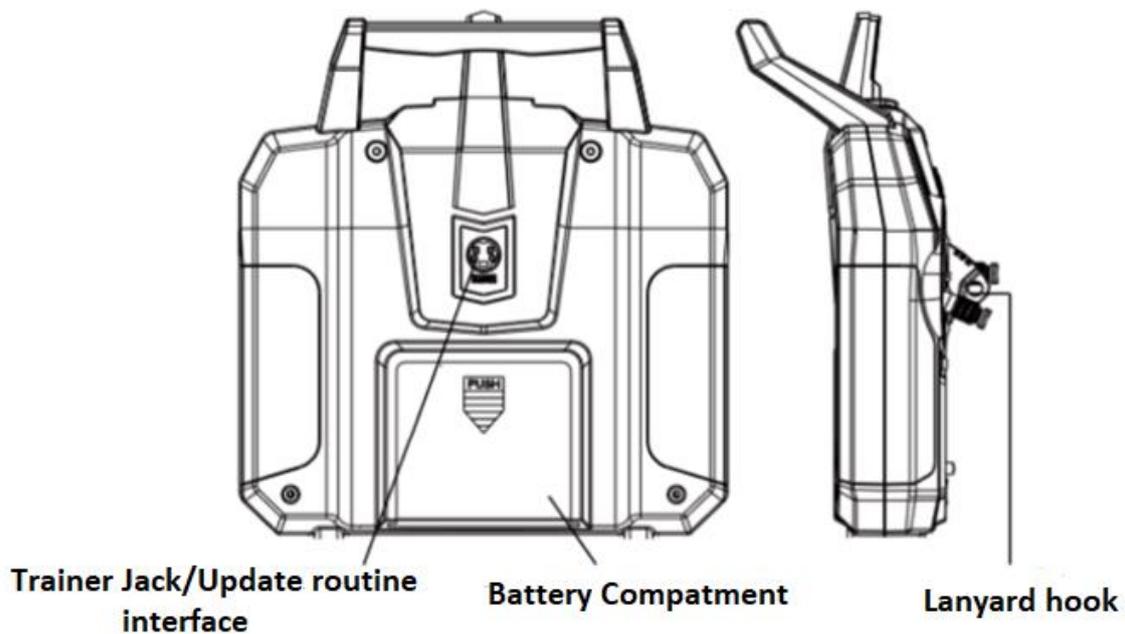
Figure 3.14: Transmitter's Side & Back View (FLYSKY FS-i6).

Figure 3.15: Receiver (FS-iA6B).

The remote control consists of:

a. Trims: We use trims to stabilize the robot. These trims are adjusted when the robot becomes unstable during work. These trims can be used for four channels. We can perform quicker trim adjustments by holding the trim in the desired position. When the trim position is in the middle, the transmitter will emit a louder tone.

b. VRA & VRB knobs: These knobs can be found at the top of transmitter. These are auxiliary channels that can be used for attaching switches to additional channels to control parts such as the movement or headlight. The image below shows that the knobs are two. The knob on left is VRA, and the knob right VRB.

c. Switches: This transmitter has four switches. They are switch A (SWA), B (SWB), C (SWC), D (SWD), and C (SWB). A, B and D are two-mode switches, while C is a third mode switch. You can use any of the two-mode switches to perform the functions of channel 5 or 6.

d. Sticks: The sticks are used for controlling the robot, every stick has a pair of functions.

e. Bind key: We use a bind-key to bind the transmitter and receiver. The black-colored binding key can be seen in the image below. This button can be found at the bottom left of the transmitter.

Table (3.1) showing the specifications of the transmitter (FS-i6). Table (3.2) showing the specifications of the receiver (FS-iA6B).

Table 3.1: Showing The Specifications of The Transmitter (FS-i6).

Channels	6
RF range	2.4055-2.475GHz
Bandwidth	500 KHz
Band	140
RF channel	<20dBm
system with 2.4GHz	AFHDS 2A/AFHDS 2B
Sensitivity	1024
Low voltage alarm	Below 4.2V
Weight	392g
Display mode	positive transflective STN type, (128 x 64) dot Matrix
Antenna length	26mm x 2
Size	174mm x 89mm x 190mm
DSC port	PS/2 PPM
Input power	6v DC 1.5AA*4
On-line update	Yes
Certificate	CE0678

Table 3-2: Showing The Specifications of The Receiver (FS-iA6B).

channels	6
RF range	2.4055-2.475GHZ
Band	140
RF channel	Less than 20dBm
2.4GHZ system	AFHDS 2A
Length of antenna	26mm*2
Weight	16.4g
Power	(4.0v-6.5v) DC
Size	(42.6*26.1*15.1)mm
Certificate	CE0678
RX-Sensitivity	-105dBm

Moreover, it is difficult to say definitively which method is better for controlling a firefighting robot without more information about the specific requirements and constraints of the project. However, here are some potential considerations for each option:

a. FS-i6 Device:

The FS-i6 is a remote-control device commonly used for model airplanes and drones. Some potential benefits of using this device to control a firefighting robot could include:

Physical Feedback: The FS-i6 has physical joysticks and buttons that provide tactile feedback to the operator, which can be important in high-pressure situations where the operator needs to make quick and precise movements.

Low latency: The FS-i6 operates on a 2.4GHz frequency, which generally provides a low-latency connection between the device and the robot. This can be important for real-time control of the robot, especially if the robot is navigating complex environments or interacting with people or objects.

Robustness: The FS-i6 is designed to withstand interference from other wireless signals and environmental factors like wind and vibration, which can make it a reliable choice for controlling a robot in challenging conditions.

However, there are also potential drawbacks to using the FS-i6 for this application:

Limited range: The range of the FS-i6 is limited to a few hundred meters, which may not be sufficient for controlling a firefighting robot in large or complex environments.

Line-of-sight requirements: The FS-i6 operates on a radio frequency, which means that there needs to be a clear line of sight between the device and the robot for it to work properly. This could be a problem if the robot wants to navigate around obstacles or through tight spaces.

Limited functionality: The FS-i6 has a limited number of buttons and switches, which may make it difficult to control complex robots or perform multiple tasks at once.

b. Wi-Fi waves:

Using Wi-Fi to control a firefighting robot would likely involve creating a wireless network between the robot and the operator's device (e.g., a laptop or smartphone). Some potential benefits of this approach could include:

Greater range: Wi-Fi networks can cover larger distances than the FS-i6, which could make it easier to control the robot in larger or more complex environments.

Flexibility: Wi-Fi networks can support a wide range of devices and software, which could make it easier to develop custom control interfaces or integrate with other systems.

Advanced functionality: Wi-Fi networks can support a wide range of data types and protocols, which could enable advanced features like video streaming, remote telemetry, or autonomous navigation.

However, there are also potential drawbacks to using Wi-Fi for this application:

Latency: Wi-Fi networks can be prone to latency and packet loss, which could make it more difficult to control the robot in real-time or perform tasks that require precise timing.

31

Interference: Wi-Fi networks can be subject to interference from other wireless signals or environmental factors like walls and metal objects, which could degrade the quality of the connection.

Security: Wi-Fi networks can be vulnerable to hacking or unauthorized access, which could be a concern if the robot is handling sensitive data or operating in secure environments.

In the end, the best option to control a fire fighting robot will depend on the specific requirements and limitations of the project, based on what we have seen of the advantages and disadvantages of each one of them, we will choose the (FS-i6) device because it is the best option.

3.2.1.11 WATER PUMP

The robot's water pump is a crucial component since it pumps water to put out fires when they start. 5 bar of pressure is used during operation. The Arduino o/p is used to control a water pump that is mounted to the robot's body.

3.2.2 ROBOT BODY

Four wheels are used to propel the robot along with firefighting tools such a pump, water tank, and water cannon. On the robot body is mounted the water tank with pump. And Arduino manages the entire process. The robot's body is 100 cm long, 80 cm weighted, and 80 cm high.

3.2.2.1   ROBOT COVER

One of the most important aspects of making a robot is the cover of the robot, because it must be made in such a way as to protect the internal parts from damage due to high temperatures during a fire. Figure (3.16) show the cover of robot.

Figure 3.16: Robot Cover.

3.2.2.2 WHEELS

The robot features two wheels in the front and two wheels in the rear, each with a 33cm diameter, for its primary construction and to achieve the desired motion and speed shown in Figure (3.17).The wheels may be used to mount the robot, and they are operated by a joystick remote control.

Figure 3.17: Robot Wheel.

3.2.2.3   WATER GUN

It is connected to the fire engine's water hose and dispenses with its own water tank in large fires, but in the case of small fires, the robot's water tank is used. The water gun has a length 50cm and a diameter of 7.5cm shown in Figure (3.18).

Figure 3.18: Water Gun.

3.2.2.4   WATER TANK

It is very simple and easy to use. It is used to store water inside, and a small pipe is used to transport water from the outlet of the pump to the water gun.

Figure (3.19) shows what the final fire extinguishing robot looks like after assembling all its parts.

Figure 3.19: Robot Firefighter.

3.3 ASSEMBLY OF MODEL

The block diagram of the suggested model, which includes the key elements employed in the firefighting robot, is shown in Figure (3.20).
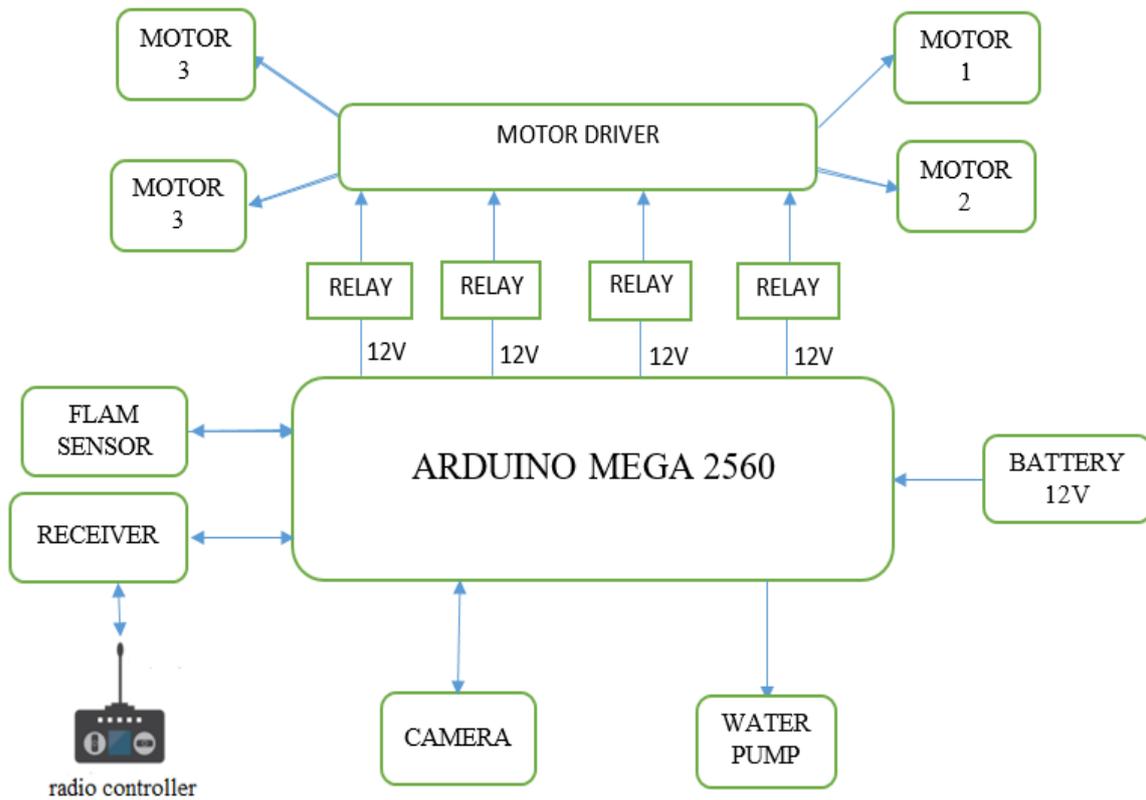

Figure 3.20: Block Diagram of the Proposed System.

The central controller is an ARDUINO MEGA. Where the flame sensor is attached, as this sensor aids in the detection of fire in the immediate area and notifies the microcontroller that a fire has occurred. A motor driver, which in turn receives the indicative from the microcontroller and sends it to the DC-motors to determine their work, is used to connect four (DC-motors) that are not directly connected to the microcontroller. These DC-motors are used to control the movement of the robot and the movement of the water gun; two of them are accountable for the movement of the robot forward and recessive, and two are responsible for the movement of the water gun to the right and left, respectively.

As for the upper side of the robot, it contains the camera responsible for transmitting a live broadcast to the event site to help us know the behavior of the fire. This video is seen through the FPV Goggles device, which acts as a receiver that receives the broadcast directly from the camera. The upper side also contains the water pump, where when a fire is detected and located by remote control, it is operated and water is pumped towards the fire and extinguished.

The robot is controlled by a remote control (FLASKY FS-i6), which acts as a transmitter of radio waves, as it sends instructions to the (FS-iA6B) receiver, which is connected to the microcontroller, and in turn the microcontroller sends signals to the required devices.

3.4 WORKING PROCEDURE

The fire suppression system is designed to focus on extinguishing fires from a distance. All moving parts of the robot are controlled by the remote control. Figure (3.21) Flowchart showing the process of detecting and extinguishing fire.

Its principle of operation is very simple. At the beginning of the process, the Arduino flame sensor will detect the presence of a flame or an infrared light source with a wavelength between 760nm - 1100nm and then the heat sensor will look to confirm the presence of fire. The user can access the fire place by means of a remote control, as it directs the robot to move, and monitoring takes place through the camera installed on the robot, where the user receives the camera image through the FPV device- goggles. When the robot reaches a suitable distance from the fire, the user instructs the Arduino to turn on the water pump and pump water towards the fire.
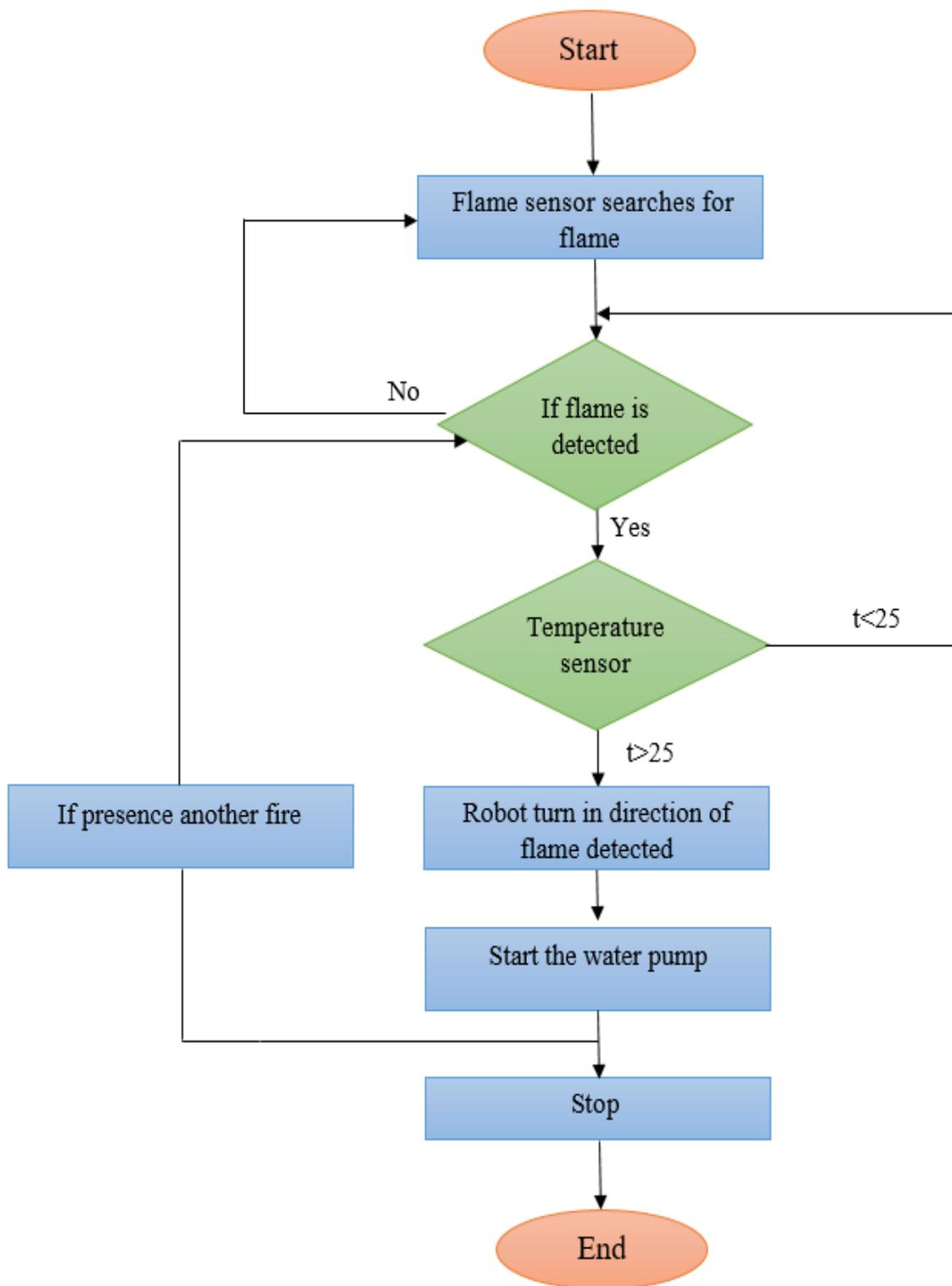
Figure 3.21: Flow Chart Showing The Process of Detecting and Extinguishing A Fire.

3.5 PROGRAMING

In order to a complete programming for the proposed model, C++ coding system has been used in the present study. A pseudo code of the program system is displays in Figure (3.22).

```
#include <Stepper.h>
const int STEPS_PER_REVOLUTION = 200;
const int SPEED = 60;
const byte PWM_PINS [] = {30, 31, 32, 33, 34};
const int NUM_PINS = sizeof(PWM_PINS) / sizeof(PWM_PINS [0]);
Stepper steppers [] = {
 Stepper (STEPS_PER_REVOLUTION, 8, 9, 10, 11),
 Stepper (STEPS_PER_REVOLUTION, 2, 3, 4, 5) };
const int NUM_STEPPERS = sizeof(steppers) / sizeof(steppers[0]);
void setup () {
for (int i = 0; i < NUM_PINS; i++) {
pinMode (PWM_PINS[i], INPUT); }
pinMode (A0, OUTPUT);
pinMode (A1, OUTPUT);
for (int i = 0; i < NUM_STEPPERS; i++) {
steppers [i].setSpeed(SPEED);  }
 Serial.begin (9600);  }
void loop() {
for (int i = 0; i < NUM_PINS; i++) {
int pwm = pulseIn(PWM_PINS[i], HIGH);
if (pwm > 0) {
Serial.println("clockwise");
steppers[i].step (STEPS_PER_REVOLUTION);  }
else if (pwm < 0) {
Serial.println("counterclockwise");
steppers[i].step(-STEPS_PER_REVOLUTION);   }  }  }
```

Figure 3.22: Pseudo Code Of The Robot.

3.6 SUMMARY

This chapter provided the methodology of the research and explained the modeling of firefighting robot in terms of electrical and mechanical parts. In addition, described the stages of assembling the modeling of a robot. Finally, discussed the robot's work in detecting and extinguishing fire.

4. RESULTS EXPERIMENTAL

4.1 INTRODUCTION

This chapter shows the results of testing the robot model with two flames, turning on and off the fire detection sensors, and analyzing the outcomes using the output of the flame sensor and the temperature sensor

4.2 EXPERIMENTAL TEST

After the completion of the firefighting robot manufacturing phase, in the Figure (4.1) a fire diagram was made with two fires, the aim of this process is to extinguish the fire and thus display the features of fire detection and extinguishing. The flame sensor gives an output of 1 if a fire is detected and an output of 0 if there is no fire.
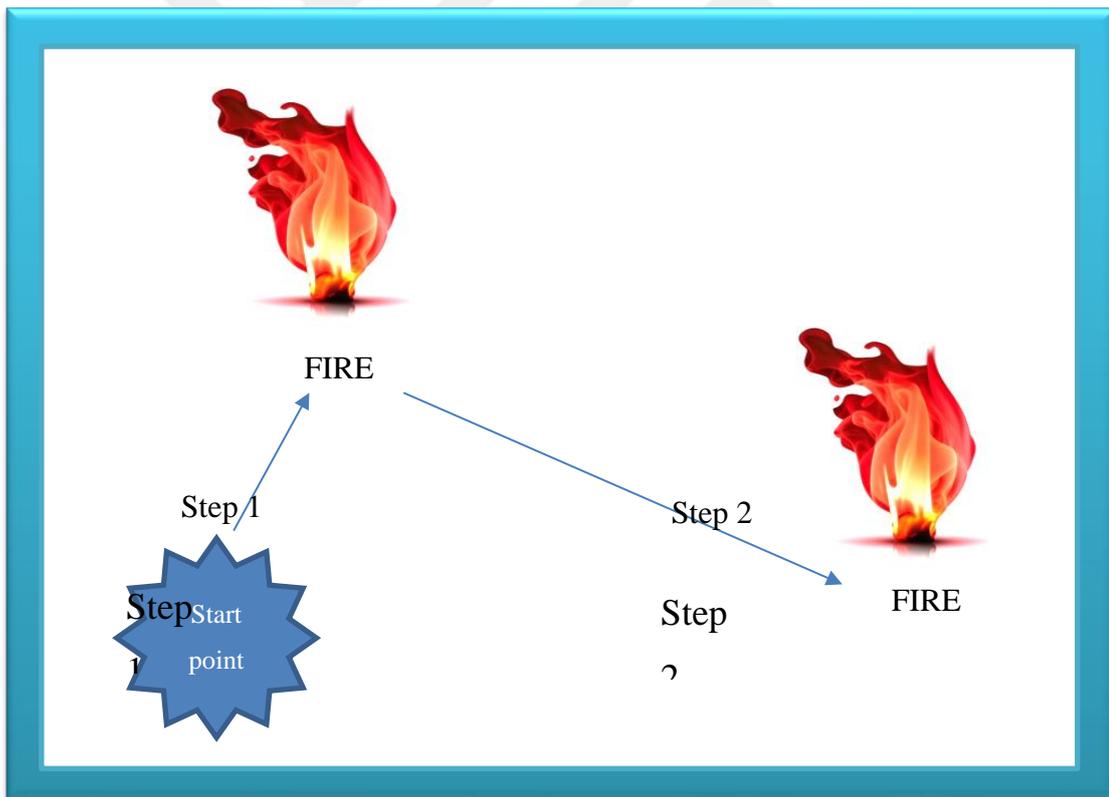

Figure 4.1: Fire Diagram.

When we turn on the robot, it starts entering data from all the sensors in the robot simultaneously. As shown in Figure (4.2) a, we note that the output of the flame sensor is

equal to 1, meaning that a fire has been detected, and this is confirmed by the temperature sensor as in Figure (4.3) a, where the temperature at the same time reaches 70 Celsius.

It is confirmed that the output of the flame sensor through the camera in the robot, which helps us determine the movement path of the robot that is controlled by the remote control, and we make the robot advance towards FIRE Step 1 to extinguish it

We stop the robot at a safe distance from the FIRE Step 1. The extinguishing process is indicated in Figure (4.2)b, where the output of the flame sensor sometimes fluctuates between zero and one. Therefore, it is ensured that the fire is extinguished accurately through the temperature sensor in Figure (4.3)b and the camera attached to the robot.

As shown in Figure (4.2), the infrared output has become equal to zero, and the fire behavior can be observed through the live broadcast of the camera to ensure the extinguishing process as seen in Figures (4.4, 4.5, 4.6 4.7 4.8 4.9, 4.10), and we also note that there is a gradual decrease in the temperature and it became less than the threshold value, which indicates the extinguishing process at the second (50) as show in Figure (4.3) c.

The robot searches for fire again, as shown in Figure (4.2) c. The output of the flame sensor is 1, which indicates the outbreak of a fire and is confirmed by observing the temperature sensor as in Figure (4.3) d, where the temperature increases dramatically.

We start by moving the robot by means of the remote control, stopping it at a safe distance from the FIRE Step 2, and starting to extinguish it

During extinguishing the fire, the readings of the flame sensor and the temperature sensor are checked simultaneously to ensure that the fire is extinguished.

Due to the movement of the robot and the intensity of the flame, there are changes in the output of the flame sensor and the temperature sensor, and the extinguishing process can be observed through the camera in the robot.

We notice in Figure (4.3) d and the temperature drop is less than the threshold value, and at the second (75) the flame sensor is zero, as in Figure (4.2), which indicates that the heat is turned off.

Figure 4.2: The Flame Sensor Output.
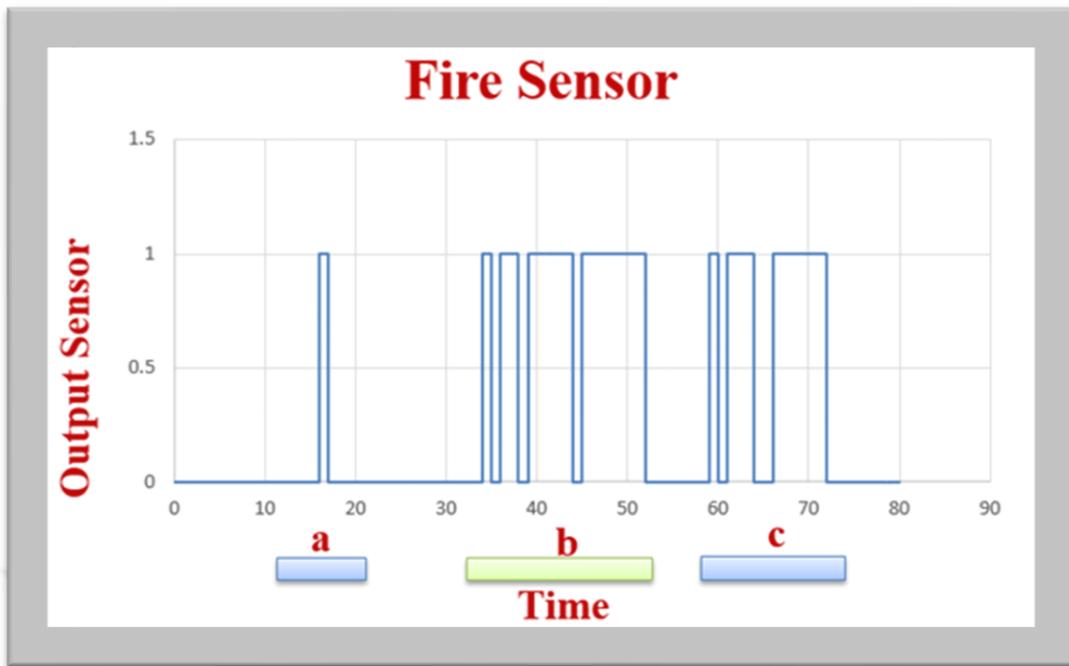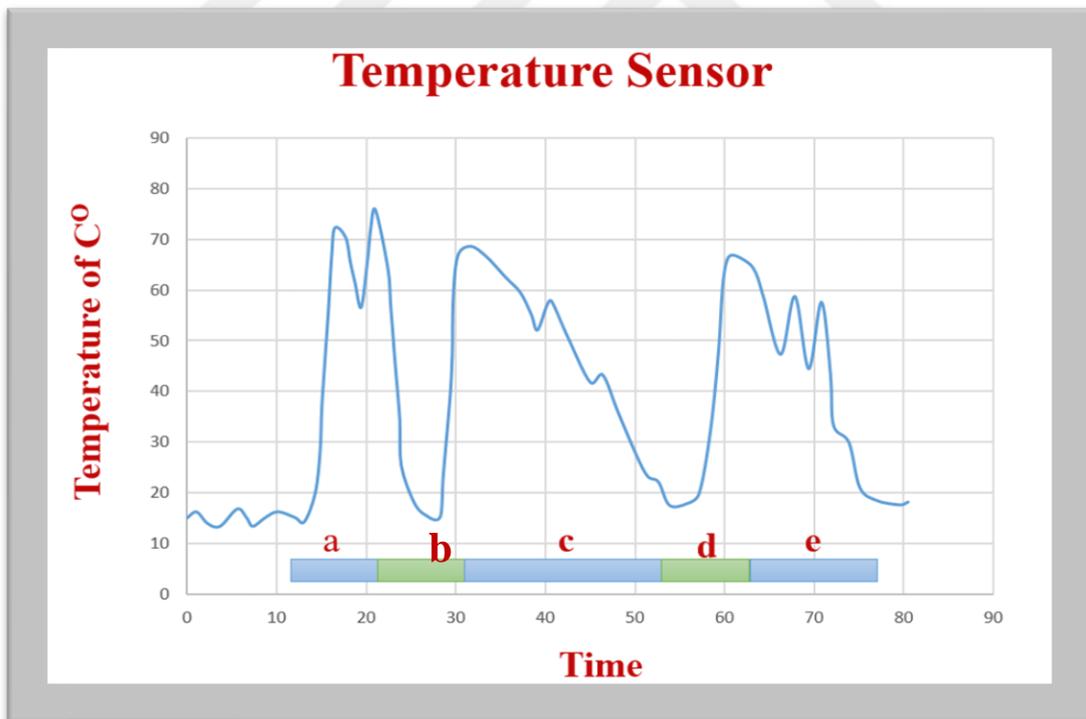

Figure 4.3: The Temperature Sensor Output.

42

Figure 4.4: Displays That The Robot Detected The First Fire.

Figure 4.5: Display That The Robot Started Extinguishing The First Fire.

Figure 4.6: Shows The Continuation of The Robot With The Process of Extinguishing The First fire.

Figure 4.7: Displays That The Robot Was Able to Extinguish The First Fire

Figure 4.8: Display the Discovery The Second Fire By Robot

Figure 4.9: Display the Start Extinguishing The Second Fire By Robot

Figure 4.10: Displays the Ability of Robot to Put Out The Second Fire

5. CONCLUSION AND FUTURE

5.1 CONCLUSION

This thesis aimed to develop and analyze an advanced firefighting robot that could assist human firefighters in extinguishing fires in challenging or dangerous areas. The robot was equipped with various sensors and tools to detect fire, identify the source of heat and flame, and use water to extinguish it. A camera attached to the robot monitored the behavior of the fire, providing a live broadcast of the location of the fire through FPV goggles. The robot was controlled remotely through the FLYSKY FS-i6 device.

To evaluate the performance of the robot, several tests and evaluations were conducted, including fire detection and extinguishing tests. The following goals were achieved:

a. The development of a robot that can be operated remotely from a secure distance and has the potential to improve firefighter safety and process efficiency. The robot's remote operation reduces the risk of injury or death to firefighters.

b. The ability of the robot to move around and locate the source of the fire has been proven through two flame sensors and temperature sensors. The robot's capability to help contain and extinguish fires before they spread reduces the risk of property damage and loss of life.

c. The remote control system used allows the user to monitor the position of the fire through the camera attached to the robot, which sends a live broadcast of the fire's location to the user through protective glasses.

d. The robot's performance evaluation demonstrated its effectiveness in firefighting operations, indicating areas for potential improvement in future versions of the robot.

Overall, this thesis presents a significant development in firefighting technology, offering a potentially life-saving tool for firefighters to combat fires in difficult or dangerous areas. The robot's effectiveness in containing and extinguishing fires, coupled with its remote operation, make it an invaluable addition to firefighting resources. Future research could focus on improving the robot's capabilities, such as increasing its speed, developing more advanced sensors, or enhancing its autonomous features.

5.2 FUTURE WORK

In the future work, there is a wide space to advance the performance of the fire extinguishing robot to work in multiple and varied environments by using more effective protection from heat by using more temperature resistant components to better protect the internal components of the robot and for better operation the scope of work of the remote control can be expanded. Moreover, the design of the robot can also be improved in terms of size, making it smaller and in a variety of shapes to reach faraway places.

REFERENCE

[1]   A. R. Wagoner, "A Sensor Ontology For The Domain Of Firefighting Robots," 2014.

[2]   H. J. G. Haynes, *Fire loss in the United States during 2014*. National Fire Protection Association. Fire Analysis and Research Division, 2015.

[3]   L. G. Kruger and J. C. Gallagher, "United States Fire Administration: An Overview," 2008.

[4]   K.-R. Kim and J.-T. Kim, "A research of the development plan for a highly adaptable FSR (Fire Safety Robot) in the scene of the fire," *Fire Sci. Eng.*, vol. 24, no. 3, pp. 113–118, 2010.

[5]   J. Kim, "Battery Management Systems for Firefighting Robots Using Simulation Modeling," Purdue University, 2016.

[6]   N. Khan, A. K. Ali, S. Van-Tien Tran, D. Lee, and C. Park, "Visual language-aided construction fire safety planning approach in building information modeling," *Appl. Sci.*, vol. 10, no. 5, p. 1704, 2020.

[7]   M. Kyrarini *et al.*, "A survey of robots in healthcare," *Technologies*, vol. 9, no. 1, p. 8, 2021.

[8]   F. Dekker, A. Salomons, and J. van der Waal, "Fear of robots at work: the role of economic self-interest," *Socio-Economic Rev.*, vol. 15, no. 3, pp. 539–562, 2017.

[9]   S. Sachi and N. Kumar, "Classification of Robots by Environment and Mechanism of Interaction," vol. 10, no. 2, pp. 227–231, 2020, doi: 552.102020/IJARSCT.

[10]   M. Ben-Ari and F. Mondada, "Robots and their applications," in *Elements of robotics*, Springer, 2018, pp. 1–20.

[11]   S. S. Priyanka, R. Sangeetha, S. Suvedha, and M. G. Vijayalakshmi, "Android Controlled Fire Fighting Robot," *Int. J. Innov. Sci. Engg. Technol.*, vol. 3, 2017.

[12]   T. AlHaza, A. Alsadoon, Z. Alhusinan, M. Jarwali, and K. Alsaif, "New concept for indoor fire fighting robot," *Procedia-Social Behav. Sci.*, vol. 195, pp. 2343–2352, 2015.

[13]   C. Fischer and H. Gellersen, "Location and navigation support for emergency responders: A survey," *IEEE Pervasive Comput.*, vol. 9, no. 01, pp. 38–47, 2010.

[14] S. Li, C. Feng, Y. Niu, L. Shi, Z. Wu, and H. Song, "A fire reconnaissance robot based on SLAM position, thermal imaging technologies, and AR display," *Sensors*, vol. 19, no. 22, p. 5036, 2019.

[15] Y. Qiu, A. Burke, M. Patel, and A. Schueler, "Smart Firefighting Technologies in Urban China," 2018.

[16] J. H. Hong, B.-C. Min, J. M. Taylor, V. Raskin, and E. T. Matson, "NL-based communication with firefighting robots," in *2012 IEEE International Conference on Systems, Man, and Cybernetics (SMC)*, 2012, pp. 1461–1466.

[17] P. Liljeback, O. Stavdahl, and A. Beitnes, "SnakeFighter-development of a water hydraulic fire fighting snake robot," in *2006 9th International Conference on Control, Automation, Robotics and Vision*, 2006, pp. 1–6.

[18] A. A. Transeth, R. I. Leine, C. Glocker, K. Y. Pettersen, and P. Liljebäck, "Snake robot obstacle-aided locomotion: Modeling, simulations, and experiments," *IEEE Trans. Robot.*, vol. 24, no. 1, pp. 88–104, 2008.

[19] E. Barinelli, J. Berman-Jolton, G. MacNeal, K. Naras, and Y. Verdeja, "Firefighting Remote Exploration Device." April, 2019.

[20] P. Liu, H. Yu, S. Cang, and L. Vladareanu, "Robot-assisted smart firefighting and interdisciplinary perspectives," in *2016 22nd International Conference on Automation and Computing (ICAC)*, 2016, pp. 395–401.

[21] Y.-D. Kim, Y.-G. Kim, S.-H. Lee, J.-H. Kang, and J. An, "Portable fire evacuation guide robot system," in *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*, 2009, pp. 2789–2794.

[22] M. D. Azhar and D. K. S. Reddy, "Android Blue Tooth Base Control Fire Fighting Robot," *IJITR) Int. J. Innov. Technol. Res.*, vol. 4, no. 5, pp. 3879–3882, 2016.

[23] M. H. Ali, S. Shamishev, and A. Aitmaganbayev, "Development of a Network-based Autonomous Firefighting Robot.," in *ICINCO (2)*, 2018, pp. 535–543.

[24] T. Rakib and M. A. R. Sarkar, "Design and fabrication of an autonomous fire fighting robot with multisensor fire detection using PID controller," in *2016 5th International Conference on Informatics, Electronics and Vision (ICIEV)*, 2016, pp. 909–914.

[25] P.-H. Chang *et al.*, "Control architecture design for a fire searching robot using task

oriented design methodology," in *2006 SICE-ICASE International Joint Conference*, 2006, pp. 3126–3131.

[26] Ö. Tok, "Design and manufacturing of a fireproof fire rescue robot," Izmir Institute of Technology (Turkey), 2008.

[27] H. P. Singh *et al.*, "Control of an autonomous industrial fire fighting mobile robot," *DU J. Undergrad. Res. Innov.*, pp. 124–130, 2015.

[28] S. Gao, Z. Zhang, Z. Zhao, and M. M. Jamali, "Vision and infra-red sensor based fire fighting robot," in *2018 IEEE 61st International Midwest Symposium on Circuits and Systems (MWSCAS)*, 2018, pp. 873–876.

[29] A. Hassanein, M. Elhawary, N. Jaber, and M. El-Abd, "An autonomous firefighting robot," in *2015 International Conference on Advanced Robotics (ICAR)*, 2015, pp. 530–535.

[30] S. Rajpal and kamaraju, "MICROCONTROLLER-BASED FIREFIGHTING TRUCK.pdf," california, 2016.

[31] M. Aliff, N. S. Sani, M. I. Yusof, and A. Zainal, "Development of fire fighting robot (QROB)," *Int. J. Adv. Comput. Sci. Appl.*, vol. 10, no. 1, 2019.

[32] A. Dhumatkar, S. Bhiogade, S. Rajpal, D. Renge, and P. Kale, "Automatic fire fighting robot," *Int. J. Recent Res. Math. Comput. Sci. Inf. Technol.*, vol. 2, no. 1, pp. 42–46, 2015.

[33] M. Kanwar and L. Agilandeeswari, "IOT based fire fighting robot," in *2018 7th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions)(ICRITO)*, 2018, pp. 718–723.

[34] J. Kim, B. Y. Lattimer, and A. L. Wicks, "Autonomous Navigation, Perception and Probabilistic Fire Location for an Intelligent Firefighting Robot," 2014.

[35] J. Raju, S. S. Mohammed, J. V. Paul, G. A. John, and D. S. Nair, "Development and implementation of arduino microcontroller based dual mode fire extinguishing robot," in *2017 IEEE International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS)*, 2017, pp. 1–4.

[36] H. U. Zaman, T. A. Khan, S. R. Falgunee, G. M. S. Rashid, and F. H. Talukder, "Autonomous firefighting robot with optional bluetooth control," in *2018 4th International Conference on Computing Communication and Automation (ICCCA)*,

2018, pp. 1–4.

[37]   J. Arifin, L. N. Zulita, and H. Hermawansyah, "Perancangan Murottal Otomatis Menggunakan Mikrokontroller Arduino Mega 2560," *J. Media Infotama*, vol. 12, no. 1, 2016.

[38]   P. Bakaráč, M. Kalúz, and L. Čirka, "Design and development of a low-cost inverted pendulum for control education," in *2017 21st International Conference on Process Control (PC)*, 2017, pp. 398–403.

[39]   A. Saha, A. Kumar, and A. K. Sahu, "FPV drone with GPS used for surveillance in remote areas," in *2017 Third International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN)*, 2017, pp. 62–67.

[40]   J. Suresh, "Fire-fighting robot," in *2017 International Conference on Computational Intelligence in Data Science (ICCIDS)*, 2017, pp. 1–4.

[41]   N. Nikhil, S. M. Shreyas, G. Vyshnavi, and S. Yadav, "Unmanned aerial vehicles (UAV) in disaster management applications," in *2020 Third International Conference on Smart Systems and Inventive Technology (ICSSIT)*, 2020, pp. 140–148.

.