AN AUTONOMOUS FIRE FIGHTING ROBOT

BY:

JOSHUA AYOMIDE OYADOKUN

20151317

A BACHELOR OF ENGINEERING PROJECT REPORT

SUBMITTED TO THE

DEPARTMENT OF MECHATRONICS ENGINEERING,

COLLEGE OF ENGINEERING,

FEDERAL UNIVERSITY OF AGRICULTURE, ABEOKUTA

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING DEGREE IN MECHATRONICS ENGINEERING

SUPERVISOR:

DR. A.T. OYELAMI

OCTOBER 2021

DECLARATION

I hereby declare that this project and report is a record of my own research work. All citations and sources of information are clearly acknowledged by means of references.

Joshua Ayomide OYADOKUN **Date**

20151317

CERTIFICATION

This is to certify that the research thesis on "**An Autonomous Firefighting Robot**" was carried out by **Joshua Ayomide OYADOKUN**, with matric number **20151317** of the department of **Mechatronics Engineering**, College of Engineering, Federal University of Agriculture, Abeokuta.

DR. A.T OYELAMI **Date**

Project Supervisor

DR. A.T OYELAMI **Date**

Head of Department

ACKNOWLEDGEMENT

Throughout the writing of this dissertation, I have received a great deal of support and assistance. I would first like to thank my supervisor, Dr A.T Oyelami for his patient support and the opportunities I was given, his expertise was invaluable in formulating my methodology and implementing it successfully. Your insightful feedback pushed me to sharpen my thinking and brought my work to a higher level.

I would also like to thank my lecturers, Prof L.O Kehinde, Prof S.J Ojolo, Engr. A.A Ishola, Engr. S.O Owoeye and Engr. (Mrs.) F.O Durodola, for their valuable guidance throughout my studies. You provided me with the tools that I needed to choose the right direction and complete my research project.

I would like to acknowledge my colleagues under the supervision of my supervisor for their valuable input and thoughts.

In addition, I would like to thank my parents for their love as it was the secret recipe to this project and also for their wise counsel and sympathetic ear. Finally, I could not have completed this dissertation without the support of my brother, my roommate and wonderful friends; Abdul-Kabir Hakeem, Ayomide Ogunsemi, Oladipupo Bamgbose, Damilola Ona-Olapo, Moyosore Adelakun who provided stimulating discussions as well as happy distractions to rest my mind outside of my research.

ABSTRACT

Fire, just like every other element can be destructive. Fire incidents and accidents have resulted in numerous loss of life and billions in loss of properties depending on the scale of the fire. Firefighters risk their lives and are often killed in action. This motivated the development of firefighting robots which will reduce the loss of lives and damages. Robots have been optimized for tasks that require strength exceeding human's own or for hazardous environments. Robotics has gained popularity due to the advancement of many technologies of computing and nanotechnologies. This project is divided into two units; the robot and the static unit. The robot is equipped with 3 flame sensors to read flames in three directions, an ultrasonic sensor to avoid obstacles, and a receiver to collect information from the static unit, a magnetometer to give the root a sense of direction, all being controlled by an Arduino Mega Microcontroller. The static unit has four flame sensors and a transmitter that sends signals to the robot unit and this unit is controlled by an Arduino Uno. In conclusion, the designed robot can help prevent the escalation of fires in home as it can detect and navigate, avoiding obstacles and extinguish flames with little or no human assistance.

TABLE OF CONTENT

DECLARATION ii
CERTIFICATION iii
ACKNOWLEDGEMENT iv
ABSTRACT v
TABLE OF CONTENT vi
LIST OF FIGURES viii
LIST OF TABLES ix
CHAPTER ONE 1
1.0 INTRODUCTION 1
1.1 BACKGROUND OF STUDY 1
1.2 PROBLEM STATEMENT 3
1.3 JUSTIFICATION 3
1.4 AIM AND OBJECTIVES 4
CHAPTER TWO 5
2.0 LITERATURE REVIEW 5
2.1 FIRE 5
2.2 CLASSIFICATION OF FIRE 6
2.2 FIREFIGHTING 7
2.3 COMPARISON OF SIMILAR WORKS 8
2.3.1 ROBOTS BUILT FOR COMPETITION 9
2.3.2 RESEARCH FIREFIGHTING ROBOT 10
CHAPTER THREE 11
3.0 MATERIALS AND METHODS 11
3.1 MATERIALS 11
3.2 DESCRIPTION OF MAJOR COMPONENTS 11
3.2.1 ARDUINO MICROCONTROLLER 11
3.2.2 FLAME SENSOR 14
3.2.3 SERVO MOTOR (SG90) 14
3.2.4 L298N MOTOR DRIVER MODULE 17
3.2.5 CHASSIS 17
3.2.6 LITHIUM-ION BATTERY 17

3.2.7 433 MHz RF TRANSMITTER AND RECEIVER MODULE 19
3.2.8 ULTRASONIC SENSOR 19
3.2.9 QMC 5883L MAGNETOMETER 19
3.3 WORKING CONCEPT OF THE FIREFIGHTING ROBOT 23
3.3.1 THE STATIC UNIT 23
3.3.2 THE ROBOT UNIT 26
3.4 SIGNAL FROM THE STATIC UNIT 29
CHAPTER FOUR 31
4.0 RESULTS AND ANALYSIS 31
4.1 RESULT ANALYSIS 31
4.2 FLAME DETECTION SYSTEM 31
4.2.1 ROBOT FLAME COVERAGE DISTANCE AND ANGLE 32
4.1.2 DIGITAL FLAME DETECTION BY THE STATIC UNIT 36
4.2 RESPONSE OF ROBOT TO SIGNALS (TRANSMISSION AND NAVIGATION).. 38
4.4 OBSTACLE AVOIDANCE SYSTEM RESPONSE 40
CHAPTER FIVE 42
5.0 CONCLUSION AND RECOMMENDATIONS 42
5.1 CONCLUSION 42
5.2 LIMITATIONS 42
5.3 RECOMMENDATIONS 43
6.0 REFERENCES 44
APPENDIX 47

LIST OF FIGURES

FIGURE 1: ARDUINO UNO AND MEGA 13

FIGURE 2: FLAME SENSOR 15

FIGURE 3: SERVO MOTOR (SG-90) 16

FIGURE 4: L98N MOTOR DRIVER 18

FIGURE 5: 433MHZ TRANSMITTER AND RECEIVER 20

FIGURE 6: ULTRASONIC SENSOR (HC-SR04) 21

FIGURE 7: MAGNETOMETER (HMC5883L) 22

FIGURE 8: BLOCK DIAGRAM OF THE STATIC UNIT 24

FIGURE 9: MAPPED PATH AND DIRECTION OF ROBOT 25

FIGURE 10: ROBOT FLAME SENSORS 27

FIGURE 11: ROBOT BLOCK DIAGRAM 29

FIGURE 12: PATHS ROBOT CAN FOLLOW 31

FIGURE 13: ROBOT FRONT VIEW 47

FIGURE 14: ROBOT BACK VIEW 48

LIST OF TABLES

TABLE 1: ROBOT'S ANGLE AND DISTANCE COVERAGE AT 20CM............................... 33

TABLE 2: ROBOT'S ANGLE AND DISTANCE COVERAGE AT 50CM............................... 34

TABLE 3: ROBOT'S ANGLE AND DISTANCE COVERAGE AT 100CM............................. 35

TABLE 4: DIGITAL FLAME DETECTION BY THE STATIC UNIT 37

TABLE 5: RESPONSE OF ROBOT TO SIGNALS... 39

TABLE 6: OBSTACLE AVOIDANCE SYSTEM RESPONSE 41

CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND OF STUDY

Firefighting has existed way long before machines and includes all processes involved in the deliberate control and prevention of the spread of fire. A firefighter can be simply put as a person that puts out fires, anyone that utilizes tools and the ability to extinguish and contain fires preventing the loss of lives and properties (National Careers Service (UK), 2017). Technology has made firefighting easier, bridging the gap between firefighting and machines thereby creating a more efficient and effective method of firefighting (Archana & Suma, 2019).

A robot is an automated intelligent mechanical being i.e. a machine, designed to behave like human or other elements to carry out complex tasks by moving physically after being programmed. Robots are beneficial in all sectors of life including medicine, rehabilitation, rescue operation and numerous industries (Day, 2018).

Robots can be divided into various groups; some are grouped based on the mode of operation. These include; Android robots which are designed to act like humans and mimic their actions, Autonomous robots are capable of acting on their own or independently (Hyung, Ahn, Cruz, & Lee, 2016), Mobile robots unlike fixed robot have a movable base and can navigate using instructions from human beings (Harik & A, 2018), Tele-robots and Telepresence robots are quite similar in operation, the technical difference between them is that the latter gives feedback in digital formats like a video, sound clip and other media data (Ahn & Kim, 2016).

The main challenges for the development of autonomous walking robots can be summarized as (Naomi, Barai, Irawan, & Daud, 2014);

1. Non-availability of energy-efficient actuators; weight to torque ratio and volume to torque ratio are still problems to build energy-efficient robots
2. Reliable and economical sensors
3. Lightweight but mechanically strong materials for construction and mechanism
4. Computers with fast and high computing power,
5. Lightweight and on-board power source for long-duration energy.

Robots are reprogrammable devices that can perform varieties of functions. A robot can be programmed to find and extinguish the fire before it goes out of control, and it would be an important tool for firefighting or even replace them reducing human causalities. The primary purpose of this robot is to be an autonomous robot, designed and programmed for fire identification and extinguishing activities, to search and extinguish fire relieving firefighters of deadly firefighting missions.

This project involves the designing and implementation of a robot that works autonomously i.e. requires no human input. It is designed to using a proportional motor control concept for the movement of the wheels, an ultrasonic sensor to detect the presence of an obstacle and manoeuvre around objects and obstacles, an infrared flame sensor which is sensitive to flame for sensing environmental temperature i.e. fire. All sensors interact with the microcontroller (Arduino Uno) which operate the water pump to spray water to extinguish the fire. The motion of the robot is controlled automatically by the output from the flame and the ultrasonic sensor. The motor driver is employed for the bidirectional control of the motors equipped within the robot.

1.2 PROBLEM STATEMENT

Fire when not controlled poses a deadly threat to homes, food, clothing, laboratory, office, factory, buildings and human life. The traditional static water sprinkler system has certain disadvantages. Some of which include, damaging of electronics, stationeries and furniture in the targeted area.

In the cases of a delay from the fire department the robot can operate autonomously, extinguishing fire after detecting it. Some available firefighting robots have either of the following disadvantages; not autonomous i.e. requires a human controller, using a fan for extinguishing, very large in terms of size, weight and low sensor range which significantly reduces the performance and increasing the cost of the robot.

1.3 JUSTIFICATION

According to Nigeria Federal Fire Service, it is estimated that Nigeria loses more than ₦5 trillion to fire in 4 years between 2013 to 2018 (Ajayi, 2019). Despite the numerous safety measures put against fire, fire outbreak happens frequently and this put lives of people as well as firefighters at risk. Robotics, one of the merits of technology advancement can help reduce loss of lives and properties to the minimum, we can replace humans for firefighting with a robot instead as this will improve firefighter efficiency and secure human lives. With a firefighting robot that operates autonomously, the need for a human controller is significantly reduced and this helps when there is no one around the site of the outbreak, there is also a need to extend the fire detection range of existing robots.

1.4 AIM AND OBJECTIVES

The overall aim of this work is to design, build and implement a firefighting mobile robot that operates semi-autonomously. The robot is to be capable of intelligent obstacle avoidance while navigating without any collision or interruption, accurately detecting fire and effectively eliminating the fire.

The specific objectives of this project are:

i. Designing a firefighting system with auto search and detection capabilities.
ii. Developing an autonomous robotic system with an automatic jet sprayer.
iii. Developing a system for obstacle avoidance navigation.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 FIRE

Fire is the visible effect of the exothermic oxidation of material which can also be called combustion. It is a chemical reaction involving the production of energy in the form of heat gotten from the bonding of oxygen with fuel resulting in the production of heat and flame or smouldering (National Wildfire Coordinating Group, 2009).

Fire affects the ecological systems of the globe as its release carbon dioxide into the environment, fire in its extensive form known as conflagration causes massive destruction.

Fire is a very useful element when created intentionally, it is used at homes for cooking, in the open for campfire or hearth fire, in agriculture for clearing land, used traditionally for signalling and ritual purpose, industrially for propulsion and forging, in waste management for incineration and cremation, another useful effect is that it aids the growth of new vegetation but when created accidentally, fire is disastrous, its negative effect includes danger to the life of human and animals, destruction of properties, making the environment unsafe through atmospheric and water pollution and in a war for mass annihilation (Lentile, *et al*., 2007).

Fire can be extinguished by removing one or more of the elements of fire, the elements necessary for any fire are air, heat and the source of fuel.

Fire can be extinguished by:

- Removing the fuel source, the fuel source can be anything ranging from a piece of paper to volatile gases
- Smothering the flame to reduce the volume of oxygen readily available to the fire, the most common method is to cover the flame completely.

- Removing heat from the fire much faster than the fire produces, a very common method is the application of water, foam or dirt.
- Applying a retardant, a fire retardant prevents the start or slow down the intensity of the fire. Examples of retardant chemicals are bromine, chlorine and nitrogen.

2.2 CLASSIFICATION OF FIRE

The most common classification of fire is based on their fuel sources. This includes, Class-A fires, Class-B fires, Class-C fires, Class-D fires and Class-K fires although this classification may vary with country. A special and different approach is needed to extinguish fires in a different class as what extinguishes Class-A fire might not be sufficient to extinguish Class-K fire or might result in a disaster which makes understanding the root cause key.

i. Class-A Fires: This is the most common and the easiest to extinguish class of fire. It involves ordinary combustible materials such as paper, clothes, wood and plastics as sources of fuel. The common control method involves the removal of heat by spraying the fuel with water or reducing the oxygen content by smothering.

ii. Class-B Fires: Class-B fires are fires from flammable liquids and gases such as gasoline, alcohol, grease and tars. As their fuel sources are hydrocarbons which have densities far less than water, the fire and fuel will float on the water and for this reason, they cannot be controlled with water but they can be extinguished with foam, powder or carbon dioxide extinguishers while some with chemical fire suppressant but it is very important to shut off the fuel source before extinguishing.

iii. Class-C Fires: Class-C fires involving energized or live electrical equipment. Using water for extinguishing is not effective and can result in short-circuiting of other components in even electrocution of the firefighter. They are best controlled by smothering with a dry agent which is the removal of oxygen after eliminating the electricity source.

iv. Class-D Fires: Class-D fires are common in domestic homes but quite common in laboratories. It involves combustible metals like potassium, uranium, sodium, magnesium and titanium and it is best controlled by using a dry powder fire extinguisher.

v. Class-K Fires: Class-K fires are common in the kitchen section of the home, common fuel sources are cooking oils and grease, animal and vegetable fats. The correct fire extinguisher to use in this instance is the Class K fire extinguisher which is the wet chemical fire extinguisher.

Fire extinguishers come in different types of chemical combustion, they include the ABC powder which is effective for Class-A, Class-B and Class-C fires, Carbon Dioxide based effective for Class-B fire, Wet Chemical suitable for Class-K fires, Water Mist suitable for Class-A, B, C, K, Foam for Class-A and Class-B, Clean Agent for Class B and Class C (Koorsen Fire & Security, 2017)

2.2 FIREFIGHTING

Firefighting is the intentional act of preventing the spread of fire by extinguishing significant unwanted fires protecting lives and properties (National Careers Service (UK), 2017).

Robots are used to maximize efficiency and safety. The Robotic Industries Association (RIA) defines a robot as a programmable, multifunctional manipulator designed to manoeuvre material, parts, tools or specialized devices through variable programmed motions for the performance of series of tasks. A robot can easily be reprogrammed to perform dangerous, repetitive or different tasks and has sensors to help react and adapt to varying environmental conditions.

Every robot must obey the three laws of robotics proposed by Isaac Asimov (Asimov, 1964), which are:

1. A robot may not injure a human being or through inaction, allow a human being to come to harm unless this would violate a higher order law.
2. A robot must obey orders given to it by human beings, except where such orders would conflict with a higher-order law.
3. A robot must protect its existence as long as such protection does not conflict with a higher-order law.

The zeroth law was also proposed afterwards which states that "A robot may not harm humanity, or, by inaction, allow humanity to come to harm."

"Stig Moberg" from ABB (Asea Brown Boveri) Robotics Company completed the first law with two more laws for industrial robots. These are given below (Wallén, 2008);

1. A robot must follow the trajectory specified by its master, as long as it does not conflict with the first three laws.
2. A robot must follow the velocity and acceleration specified by its master, as long as nothing stands in its way and it does not conflict with the other laws.

2.3 COMPARISON OF SIMILAR WORKS

An autonomous firefighting robot is not entirely new as similar works have been done on it before all using different simple and advanced technologies to achieve an independent robot with fire extinguishing abilities providing safer working and living environments.

Autonomous robotic navigation is a well-researched area of study that deals with the exploration of a robot guiding its way around the object to a destination by obtaining useful information about its environment and navigating without human interaction.

There are numerous firefighting robots available now ranging from small-sized robots capable of navigating through pipes to industrial fire robots big enough to extinguish a multi-storey fire or forest fire.

There are firefighting robots designed for competitions which are unfortunate since developers want to protect their interest and they keep vital information about the operational principle that can help change the scope of firefighting.

2.3.1 ROBOTS BUILT FOR COMPETITION

The firefighting robot (Hasimi, Zuha, Suhaidi, & Hamiruce, 2010), designed a three-wheeled (1 dummy wheel) autonomous robot which has three motors, two of which are for the robot motion and the other for ball suction and fire extinguishing with the aid of a centrifugal fan and ball suction. Hardware components of the robot consist of sensors such as photoelectric sensors, fibre optic sensor and RGB colour sensors, an LCD, power supply module, motor driver and the PIC16F877A which is the robot's microcontroller. The PIC16F877Ais a traditional type of microcontroller that only supports 8 channels and unlike the Arduino, it requires lengthier code and needs an extra plugin to connect peripheral hardware devices, the robot navigated through a maze performing forward, reverse, left and right motion effortlessly, it was also able to search of fire puts it out and also use it photoelectric sensors to identify various colours of tennis balls and collect them.

Another is a robot designed for the competition is the Trinity College Fire Fighting Robot Competition by (Sheets & Sutphin, 2019) where they also create an autonomous robot that works around a replica house. This robot was not only able to detect fire; it is also sensitive to fire alarms too. This robot was equipped with LEDs to provide visual about the environmental conditions and will light up the red LED if it detects a fire, it uses STM32F446RE IC for processing abilities, a short-range infrared fire sensor, microphone, line following sensor. This robot had issues with motion has the line following sensor had to be adjusted to be close to performing optimally.

2.3.2 RESEARCH FIREFIGHTING ROBOT

Development of firefighting robot (QRob) by (Mohd, Nor, Yusof, & Azavitra, 2019). The QRob uses Arduino Uno as its microcontroller is equipped with a webcam for visual feedback, an ultrasonic sensor for obstacle avoidance, a flame sensor, a water pump, a DC motor and also a transmitter and remote control for controlling the robot remotely. The QRob has a limited flame sensing range of 40cm but the can be worked about by using a human operator to manually monitor the robot by using a camera that connects to a smartphone or remote devices and control it to the site of the flame.

Design and Fabrication of an Autonomous Fire Fighting Robot with Obstacle Detection and Fire Detection Using Arduino by (Archana & Suma, 2019): This robot was designed with locally available materials, unlike other robots this design incorporate an LM35 temperature sensor, the major limitation to this design is also the sensing range.

Intelligent Wireless Fire Extinguishing Robot by (Akib & Sathya, 2017) took advantage of the internet of things to make an internet controlled robot. It uses Arduino Uno for controlling the robot and Arduino Yun that has built-in Ethernet and Wi-Fi for external communication and also gives video feedback through the webcam.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 MATERIALS

This project is configured to use the Arduino microcontroller as its brain which will control all other functions. The major components used are as listed below:

1. Arduino Mega
2. Arduino Uno
3. Flame Sensor
4. Servo Motor (SG90)
5. L298N Motor Driver Module
6. Robot Chassis with motors and wheels
7. Extinguisher Storage
8. Lithium-ion Battery
9. Water Pump
10. HC – 12 433MHz Transceiver Module
11. Ultrasonic Sensor
12. QMC 5883L Magnetometer

3.2 DESCRIPTION OF MAJOR COMPONENTS

3.2.1 ARDUINO MICROCONTROLLER

Arduino is an open-source programmable circuit board that can be integrated into a wide variety of projects both simple and complex.

Arduino Uno shown in Figure 1 is a microcontroller development board that uses the ATmega328P microcontroller having 14 digital input/output pins of which 6 can be used for pulse width modulation (PWM), 6 analogue input/output pins, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button.

Arduino Mega shown in Figure 2 below is a microcontroller development board that uses the ATmega 2560 microcontroller consisting of 54 digital input/output pins of which 15 of those pins can be used for pulse width modulation (PWM), 16 analog input/output pins, 4 Universal Asynchronous Receiver Transmitter (UARTs), a 16MHz crystal oscillator and also 6 interrupts. The Arduino microcontroller is designed to control the circuit logically. Arduino can be programmed using C++ language to read the input, process the program, and produce many outputs based on our necessity.

1.2.1.1 TECHNICAL SPECIFICATION OF ARDUINO UNO AND MEGA

PROPERTIES	**ARDUINO MEGA**	**ARDUINO UNO**
Microcontroller	ATmeg2560	ATmega328P
Operating Voltage	5V	5V
Flash Memory	256 KB	32KB
SRAM	8 KB	2KB
Clock Speed	16MHz	16MHz
Analog IN Pins	8	6
EEPROM	4 KB	1KB
DC Current per I/O Pins	20mA	20mA
Input Voltage	7 – 12 V	7 – 12 V
Digital I/O Pins	54 (14 PWM)	14 (6 PWM)
PWM Output	6	6
Power Consumption	11.85mA	11.45mA
PCB Size	101.52 x 53.3mm	68.6 x 53.4mm

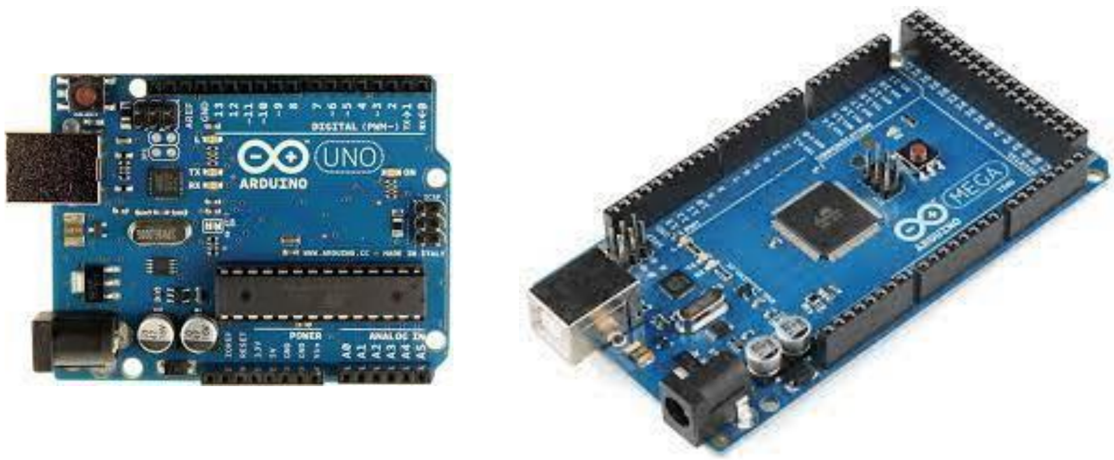

FIGURE 1: ARDUINO UNO AND MEGA

3.2.2 FLAME SENSOR

The Flame sensor shown in Figure 2 used in this project is infrared-based and would detect the presence of fire by the release of IR during combustion It’s important to note that it would also detect other sources of infrared rays with a wavelength in between 760 nm to 1100 nm range of light source.

When fire burns it emits a small amount of Infra-red light, this light will be received by the Photodiode (IR receiver) on the sensor module. Then we use an Op-Amp to check for a change in voltage across the IR Receiver, so that if a fire is detected the output pin (DO) will give 0V(LOW) and if the is no fire the output pin will be 5V(HIGH).

The sensor has a detection angle is 60 degrees and should keep a safe distance from the flame to prevent permanent damage to the sensor.

3.2.3 SERVO MOTOR (SG90)

Servo motors shown in Figure 3 are high torque, tiny and lightweight with high output power motors used because of the ease to control their rotation. Servo motors have a geared output shaft which can be electrically controlled to turn one (1) degree at a time rotating a total of approximately 180 degrees (90 in each direction. The signal which is the third pin after the VCC and GND is used to control the servo motor, turning its shaft to any desired angle.

FIGURE 2: FLAME SENSOR

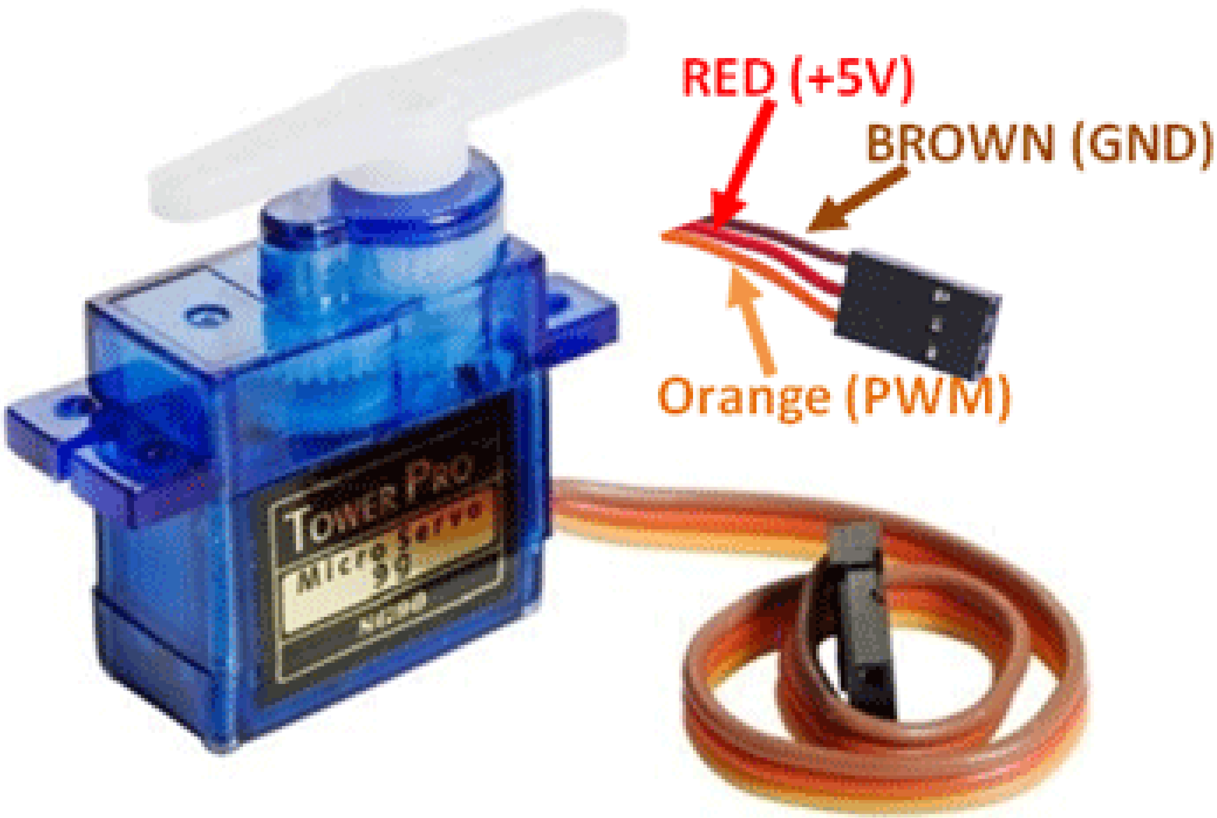

FIGURE 3: SERVO MOTOR (SG-90)

3.2.4 L298N MOTOR DRIVER MODULE

The L298N shown in Figure 4 is a popular motor driver IC used to drive motors. A single L298N IC is capable of running two DC motors at the same or different speeds concurrently; also the direction of these two motors can be controlled independently with operating voltage less than 35V and operating current less than 2A.

3.2.5 CHASSIS

A chassis shown is the load-bearing framework of an artificial object, which structurally supports the object in its construction and function. It holds the underpart of a motor vehicle, on which the body is mounted and the running gear such as wheels and transmission just to mention a few.

3.2.6 LITHIUM-ION BATTERY

A lithium-ion battery or Li-ion battery is a type of rechargeable battery which are commonly used for portable electronics and electric vehicles. Li-ion batteries can be recharged hundreds of times having higher energy density, voltage capacity and lower self-discharge rate than other rechargeable batteries. This makes for better power efficiency as a single cell has longer charge retention than other battery types. The power requirements for this project are 9v each to power the two Arduino boards and the motor driver module. All other components will take power from their respective Arduino boards.

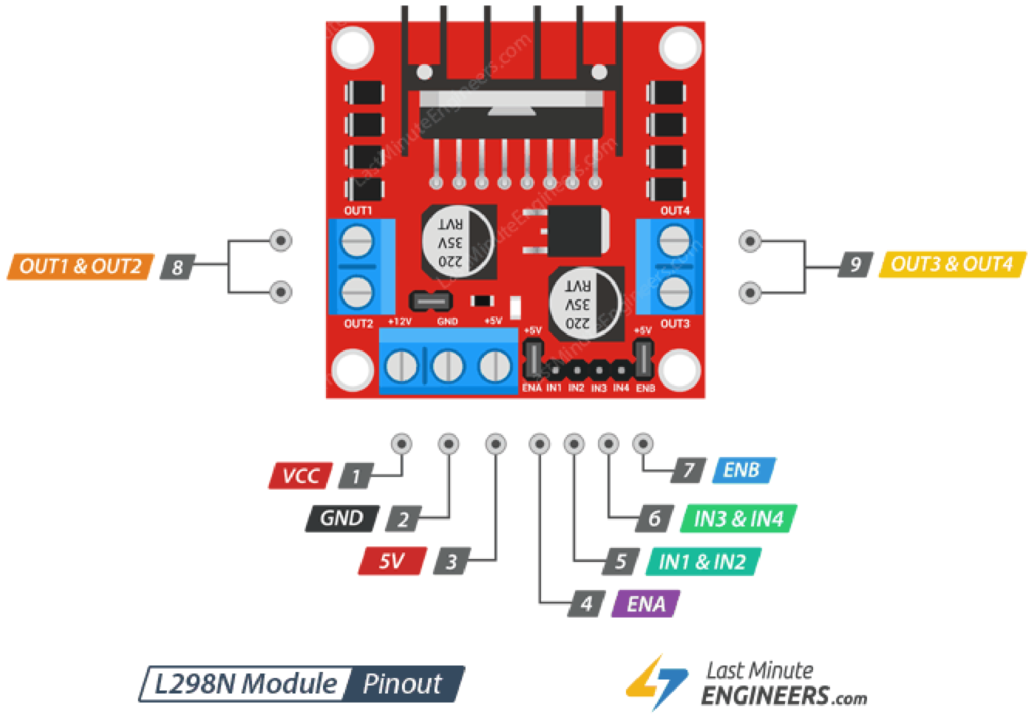

FIGURE 4: L298N MOTOR DRIVER

3.2.7 433 MHz RF TRANSMITTER AND RECEIVER MODULE

The 433MHz radio modules shown in Figure 5 have a separate transmitter and receiver that operate around the radio wave frequency band. This module communicates using the 433MHz frequency band, the transmitter and receiver module are used to send and receive radio signals between any two devices. The transmitter module sends the data from the transmitter end and the receiver module receives that data at the receiver's end.

3.2.8 ULTRASONIC SENSOR

An ultrasonic sensor shown in Figure 6 is an electronic device that uses ultrasonic waves to measures the distance of a target object by emitting ultrasonic sound waves and converts the reflected sound into an electrical signal. The Arduino ultrasonic sensor is a 4 pin module, whose pin names are VCC, Trigger, Echo and Ground and is made up mainly of two main parts: the transmitter and the receiver. The Ultrasonic transmitter transmits an ultrasonic wave, this wave travels in the air and when it gets objected by any material it gets reflected toward the sensor this reflected wave is observed by the Ultrasonic receiver module.

3.2.9 QMC 5883L MAGNETOMETER

QMC5883L shown in Figure 7 is a 3-axis digital compass that can be used to measure the magnetization of a magnetic material, measure the strength, the direction of the magnetic field at a point in space.

The QMC5883L uses a magneto-resistive sensor arranged in a bridge circuit, which is made of nickel-iron (Ni-Fe magnetic film) material which is highly sensitive to magnetic fields and their change in voltages is used to get the magnetic field direction in space.

FIGURE 5: 433MHZ TRANSMITTER AND RECEIVER

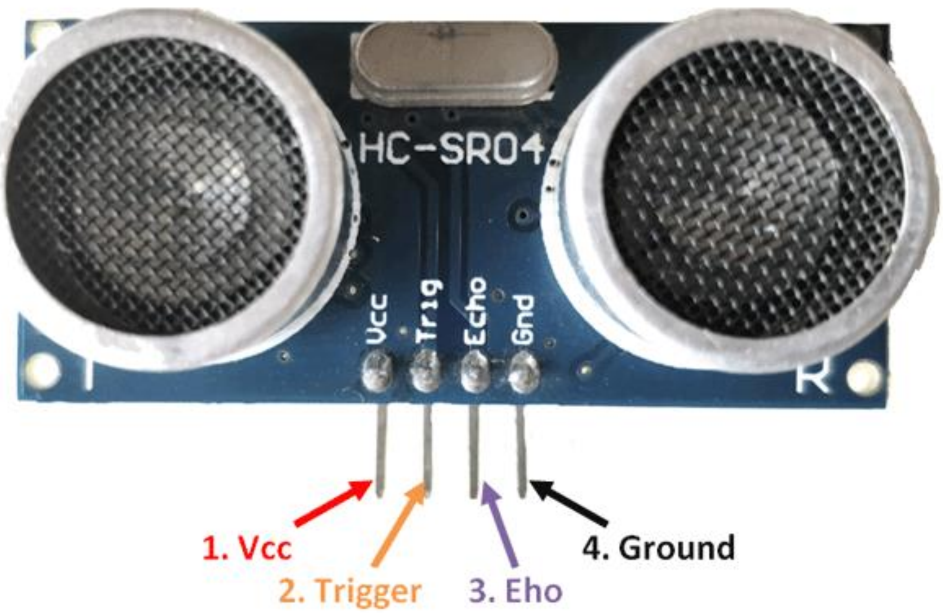

FIGURE 6: ULTRASONIC SENSOR (HC-SR04)

FIGURE 7: MAGNETOMETER (HMC5883L)

3.3 WORKING CONCEPT OF THE FIREFIGHTING ROBOT

The working concept of the project is divided into two parts; the robot unit and the static sensitivity range extension unit.

3.3.1 THE STATIC UNIT

This unit is made up of an Arduino Uno, four flame sensors, a 433MHz transmitter and a power supply.

The four flame sensors are positioned at the corners of the designed structure and they serve as an additional fire sensing unit to aid the robot. When any of these sensors detect fire in this sensing range, the Arduino Uno microcontroller sends a signal to the robot unit to alert it, this signal will contain the location of the sensor that sensed the fire so that the robot can proceed to that location and extinguish the fire.

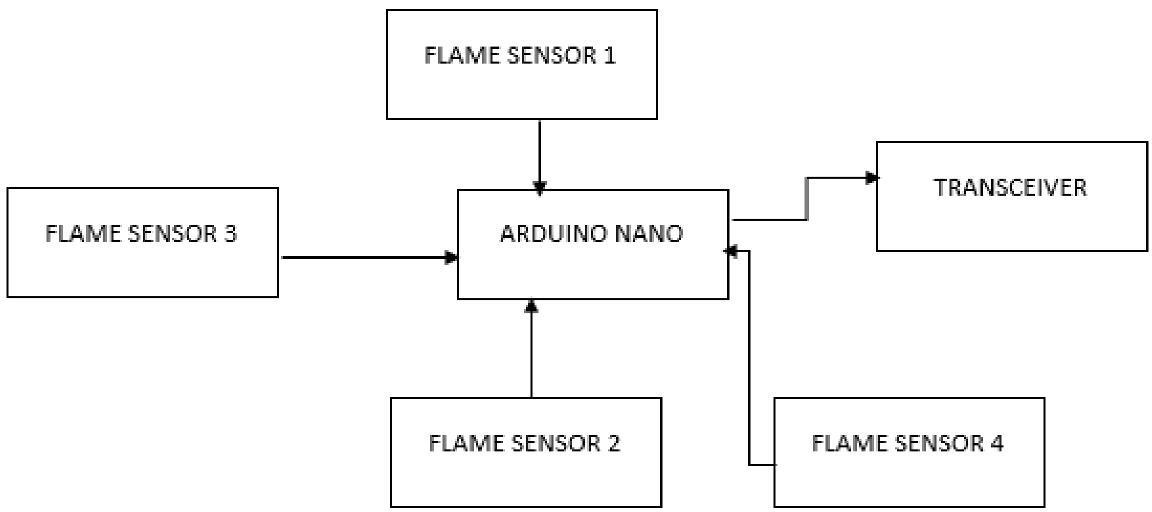

FIGURE 8: BLOCK DIAGRAM OF THE STATIC UNIT

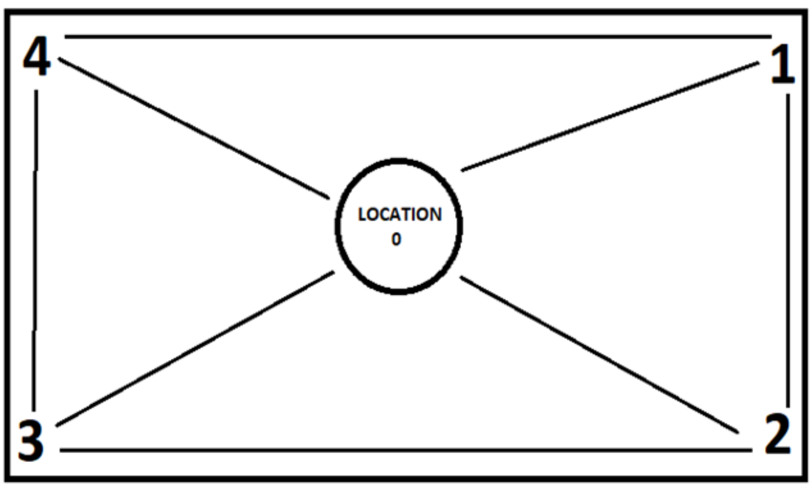

FIGURE 9: MAPPED PATH AND DIRECTION OF ROBOT

3.3.2 THE ROBOT UNIT

The robot unit consists of the chassis with motor and wheel, the Arduino Mega, three flame sensors, servo motor, motor driver, extinguisher storage, power supply, water pump, RF receiver, magnetometer compass and the ultrasonic sensor.

The main processing of this section is the Arduino Mega microcontroller, it receives signal input from the flame sensors to complete the flame detection system, from the ultrasonic sensor to complete the obstacle avoidance system and the RF receiver to adequate process incoming signal and complete the transmission system, the water pump to extinguish the flame in its surroundings., the magnetometer to process the sense of the location of the robot.

The motion of the robot is controlled based on the Arduino Mega through the L293D module motor driver on the information received from the flame, ultrasonic sensor and RF receiver.

Flame sensors have a sensing range of about 1m and an angle of 60°, so we combine three flame sensors to give a total coverage angle of 180°. In this way, they don't only increase the sensitivity range but also give the robot some sense of direction; left, forward, right.

The ultrasonic sensor is positioned on the chassis at the front of the robot. The main function of the ultrasonic sensor is to sense the presence of obstacles in the robot paths, obstacles may include a wall or a solid object that throw the robot out of balance.

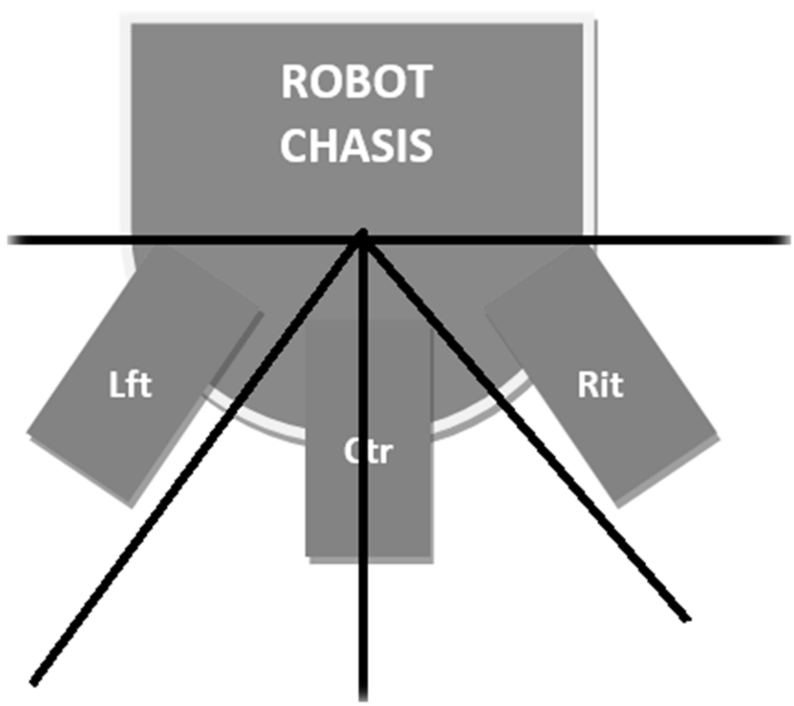

FIGURE 10: ROBOT FLAME SENSORS

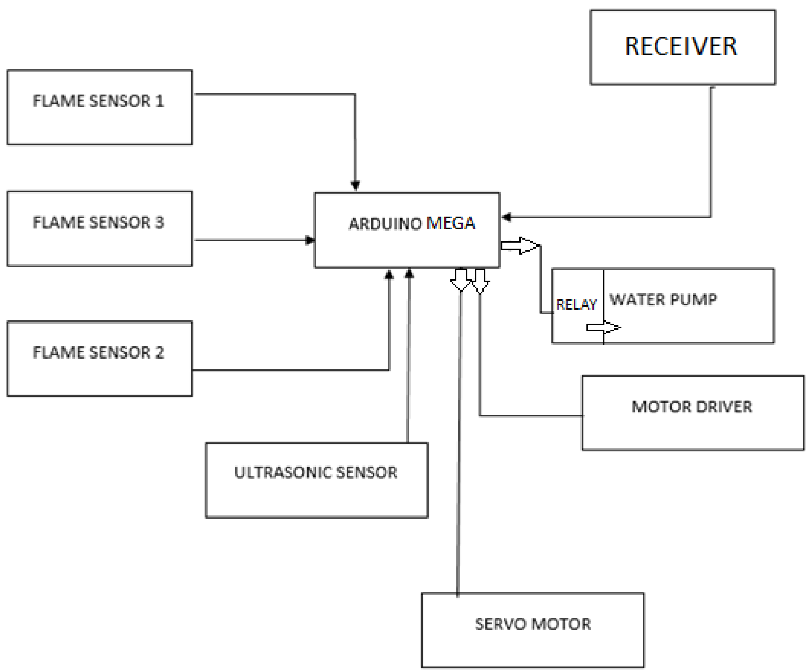

FIGURE 11: ROBOT BLOCK DIAGRAM

3.4 SIGNAL FROM THE STATIC UNIT

If the fire is sensed by the static unit, the robot proceeds towards it in the direction of the sensing sensor using its ultrasonic sensor to avoid obstacles and extinguishes it by powering the water pump and servo motor that spray water in a sweep motion.

The environment where this robot will be implemented will be mapped out into five key locations, which are;

0, the initial location and 1,2,3,4 are all corners of the environment.

The bearing of all locations from any location is coded into the robot so that the robot can effectively travel from any location to any location.

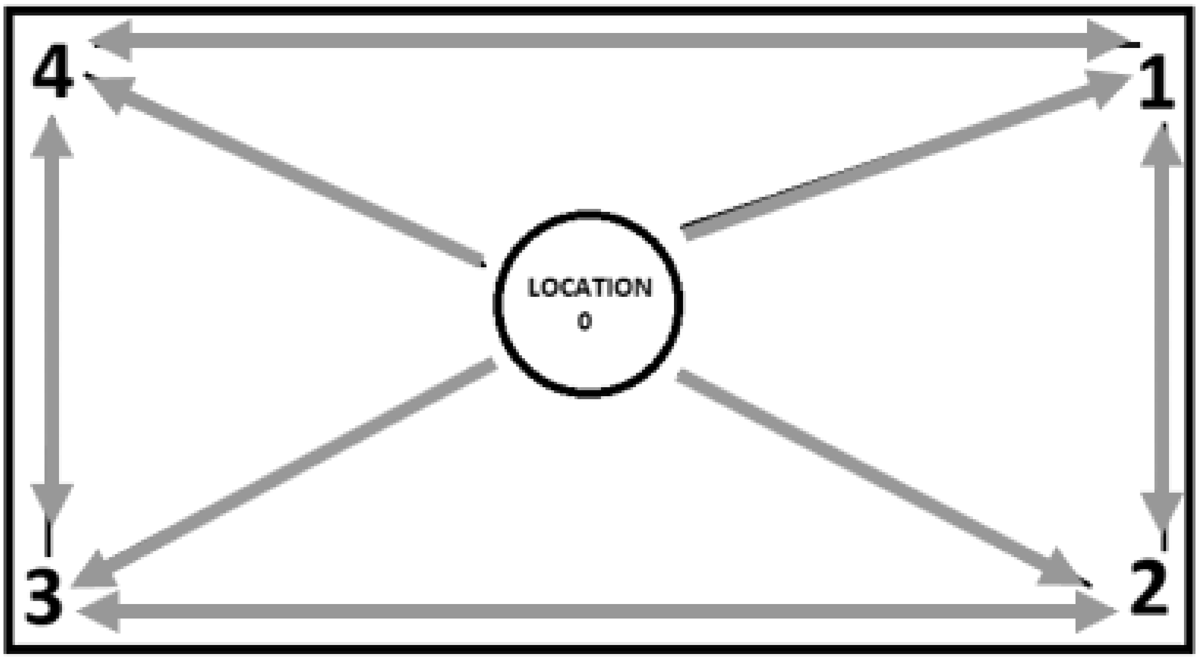

FIGURE 12: PATHS ROBOT CAN FOLLOW

CHAPTER FOUR

4.0 RESULTS AND ANALYSIS

4.1 RESULT ANALYSIS

This design was implemented on a four-wheel drive chassis, the chassis houses all the components which includes the motor, batteries, motor shields, sensors, magnetometer, transceiver, servo motors and protects them from any damage from the fire source. The robot successfully detected multiple flames from around it and also receivers signals from the transceiver at the static units, navigates towards the flame by the directional aid of the compass and extinguished the flame from a safe distance.

Analysis in this chapter will be broken down into subsystems of the autonomous firefighting robot. These subsystems include:

1. Flame Detection System
2. Obstacle Avoidance System
3. Navigation System
4. Transmission System

4.2 FLAME DETECTION SYSTEM

The flame detection system is further broken down into three

1. Analog flame detection by the robot unit
2. Digital flame detection by the static unit

1. Analog flame detection by the robot unit

The analog flame sensor operates differently from the digital flame sensor as it sends output in the range of 0 – 1023, depending on the intensity and distance from the flame where 0 reads the highest intensity or the flame is closest to the robot and 1023 means that the robot is far away from the flame or that there is no flame at all.

4.2.1 ROBOT FLAME COVERAGE DISTANCE AND ANGLE

This test is to determine the coverage distance and angle of the three analog flame sensors installed on the robot. According to the datasheet, each flame sensor has a coverage angle of 60° and can sense flame up to 100cm away and this test is carried out to ensure this data is accurate.

This robot uses three flame sensors and is arranged in such a way to provide it with 180° of flame detection, this angle is measured from the leftmost sensor and this test seeks to confirm the flame detection angle and range.

Flame is introduced at varying distances and angles to test the flame sensor’s sensitivity, angle and distance coverage. This is to determine the effect of distance on the sensors. i.e. how efficient the sensors are concerning distance and the result obtained from this test is shown in table 1, table 2 and table 3 below.

TABLE 1: ROBOT'S ANGLE AND DISTANCE COVERAGE AT 20CM

S/N	Angle (°)	Response Time (sec)	Sensor Sensitivity (cm/sec)	Sensor Reading	Test Result
1	0	2	0.1	120	PASS
2	20	1	0.05	79	PASS
3	40	1	0.05	70	PASS
4	60	1	0.05	69	PASS
5	80	1	0.05	55	PASS
6	100	1	0.05	57	PASS
7	120	1	0.05	69	PASS
8	140	2	0.1	70	PASS
9	160	2	0.1	75	PASS
10	180	2	0.1	82	PASS

TABLE 2: ROBOT'S ANGLE AND DISTANCE COVERAGE AT 50CM

S/N	Angle (°)	Response Time (sec)	Sensor Sensitivity (cm/sec)	Sensor Reading	Test Result
1	0	8	0.16	550	PASS
2	20	6	0.12	444	PASS
3	40	4	0.08	311	PASS
4	60	1	0.02	250	PASS
5	80	1	0.02	200	PASS
6	100	1	0.02	211	PASS
7	120	2	0.04	222	PASS
8	140	4	0.08	322	PASS
9	160	6	0.12	400	PASS
10	180	8	0.16	500	PASS

TABLE 3: ROBOT'S ANGLE AND DISTANCE COVERAGE AT 100CM

S/N	Angle (°)	Response Time (sec)	Sensor Sensitivity (sec/cm)	Sensor Reading	Test Result
1	0	0	0	1024	FAILED
2	20	10	0.1	250	PASS
3	40	8	0.08	200	PASS
4	60	2	0.02	150	PASS
5	80	1	0.01	137	PASS
6	100	1	0.01	136	PASS
7	120	4	0.04	138	PASS
8	140	6	0.06	151	PASS
9	160	8	0.08	200	PASS
10	180	0	0	1024	FAILED

From the test result above, this firefighting robot has a flame coverage of about 180° and is effective in the range of 10cm to 50cm.

4.1.2 DIGITAL FLAME DETECTION BY THE STATIC UNIT

In this section, we will be analysing the sensitivity of static unit flame sensors.

A flame will be staged at each corner of the room that has the flame sensor and we will confirm the response of the robot and the result obtained from this test is shown in table 4 below.

The digital flame sensor operates in the digital level of 0 and 1 which can also be said to be at HIGH or LOW, where HIGH interprets that the robot is far away from the flame or that there is no flame at all and LOW meaning that highest intensity or the flame is closest to the robot and these readings can be adjusted by varying the potentiometer on the flame sensor.

TABLE 4: DIGITAL FLAME DETECTION BY THE STATIC UNIT

S/N	Sensor Location	Distance (cm)	Response Time (sec)	Sensor Sensitivity (sec/cm)
1	**A**	50	5	0.25
2		75	8	0.11
		Average Sensitivity =		0.18
3	**B**	10	1	0.10
4		30	4	0.13
		Average Sensitivity =		0.12
5	**C**	10	1	0.10
6		20	2	0.10
		Average Sensitivity =		0.10
7	**D**	50	6	0.12
8		75	9	0.12
		Average Sensitivity =		0.12

The digital flame sensors installed at four different corners have an average resolution of about 0.13sec/cm, and this is more than enough time to accurately read the sensor value for processing the robot navigate to areas that need concerns.

4.2 RESPONSE OF ROBOT TO SIGNALS (TRANSMISSION AND NAVIGATION)

This test was carried out by triggering the flame sensors connected to the static unit and measuring the time taken for the robot to respond.

There are five different locations as stated in the methodology, the robot will be placed at one each time and the static unit sends a signal for the remaining four locations, the distance between locations is also measured

For the obtained results, we can obtain the signal response speed and also the robot's navigation speed too and the result obtained from this test is shown in table 5 below.

TABLE 5: RESPONSE OF ROBOT TO SIGNALS

S/N	Current Location	Static Unit Signal	Distance between location (cm)	Response Time (sec)	Response Speed (cm/sec)	Travel Time (sec)	Robot Navigation Speed (cm/sec)
1	0	1	250	5	50	15	16.7
2		2	250	6	41.7	13	20.8
3		3	250	5	50	14	17.9
4		4	250	8	31.3	17	14.7
5	1	2	265	10	26.5	25	10.6
6		3	500	15	33.3	30	16.7
7		4	400	17	23.5	25	16
9	2	1	265	9	29.44	22	12.1
10		3	400	15	26.7	27	14.8
11		4	500	16	31.25	31	16.1
12	3	1	500	17	29.4	33	15.2
13		2	400	16	25	28	14.3
14		4	265	10	26.5	27	9.8
15	4	1	400	17	23.5	30	13.3
16		2	500	20	25	32	15.6
17		3	265	10	26.5	30	8.3

4.4 OBSTACLE AVOIDANCE SYSTEM RESPONSE

This test was conducted by placing reasonably obstacles in the robot path and analysing the response.

The programmed response of the robot is to halt if it's 30cm away from an obstacle, check if the left path is free by rotating the ultrasonic sensor that holds the ultrasonic sensor towards the left and then read the distance, it then records thus distance and rotates the ultrasonic sensor to the right and also checks the distance towards the right. It then compares the two values and takes the path with a clearer path and the result obtained from this test is shown in table 6 below.

This test will analyse the system's obstacle response with these three steps

1. The distance of detection: This has to do with at what distance was the robot able to sense the presence of the obstacle and halt its motion.
2. The obstacle distance for both the left and right path
3. Which path the robot took?

TABLE 6: OBSTACLE AVOIDANCE SYSTEM RESPONSE

S/N	Obstacle Distance (cm)	Distance Robot Halted (cm)	Left Path Obstacle Distance	Right Path Obstacle Distance (cm)	Correct Path to take	Path Robot took	Is robot correct?
1	100	28	70	80	Right	Right	Yes
2	50	25	50	20	Left	Left	Yes
3	30	30	60	65	Right	Right	Yes
4	15	15	0	60	Right	Right	Yes

For the obstacle avoidance test, an environment that contains various obstacles was established and from the result, it was observed that the obstacle avoidance structure and algorithm of the system could satisfy the requirements of the fire detection robot.

The performance of the robot was tested four times in the established test environment and the robot always took the right path.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The developed robot is a prototype of a semi-advanced firefighting robot with a limited budget. Despite the limited budget, the robot accurately and efficiently avoids obstacles, detect fire with wavelength range 760 to 1100 nm from 10 cm up to 100cm and extinguishes them according to the tests conducted fire detection robot passed the functions tests successfully. This makes it an improvement to the existing sprinkler system that are used extensively in homes and offices. Building an autonomous mobile robot navigation system is a very challenging task especially when working in an unknown or unmapped environment. The system relies on multiple sensors to acquire information about the environment it is navigating in. With the information gained it can generate desired behaviours to complete certain objectives.

The robot can operate in an environment which is out of human reach in a very short time, the delay gotten from the result is quite minimal and directly solves a problem by preventing the escalation of fires by extinguishing them

5.2 LIMITATIONS

Some of the limitations observed while carrying out this research work are as listed below;

1. The IR-based Flame sensor is best used in dark environments because it is also sensitive to sun reflection and can give a false reading when used outdoors.
2. The output of the flame sensor varies with the robot's positon (close or farther) and intensity of fire which means it can output X for a match fire 10 cm away from it and the same X output when it is 25cm away from a burning paper.

3. It was impossible to implement the GPS module for indoor use because it can't relay information to the satellite in the sky without inference from the walls and roofs of buildings and get the exact coordinate of the robot.
4. An alternative to using a GPS module was to use a NodeMCU ESP8266 with Google or any other Geo-Location API which I also tried but the accuracy from this method was about 120m and it isn't suitable for our uses.
5. The QMC5883L Compass module used in this project like any other compass module works based on the magnetic north of the earth and would get false reading it detects a magnet or heavy presence of magnetic material.
6. The libraries used for the HC-12 (433MHz) transmitter, the HC-SR04 ultrasonic sensor and the in-built servo motor library all made use of the same interrupt of the microcontroller and I had to edit the core libraries to make sure it worked.

5.3 RECOMMENDATIONS

The following recommendations are hereby proposed for further enhancement pf the functionalities of the developed system:

1. Further research should be done on improving the accuracy of detection of the flame sensor by combining or using other methods of flame detection like image processing. For example, a hydrogen flame generates a lot of UV radiation with very little IR and this type of flame won't be easily detected by this system, but a coal fire that generates little UV and a high amount of IR radiation will easily be.
2. Further research should be done on how to integrate transceiver with a GPS module without interference.

6.0 REFERENCES

Ahn, J., & Kim, G. J. (2016). Remote collaboration using a tele-presence mobile projector robot tele-operated by a smartphone. *IEEE/SICE International Symposium on System Integration (SII)*, 236-241.

Ajayi, O. (2019, November 30). *Nigeria Fire Service*. Retrieved from Vanguard : https://www.vanguardngr.com/2019/11/nigeria-loses-n5trillion-to-fire-in-4-yrs

Akib, I., & Sathya, P. (2017). Intelligent Wireless Fire Extinguishing Robot. *International Journal of Control Systems and Robotics*, 214 -220.

Alifff, M., Samsiah, N., Yusof, M., & Zainal, A. (2019). Development of Fire Fighting Robot (QRob). *International Journal of Advanced Computer Science and Applications (IJACSA)*, 10.

Archana, B. T., & Suma, K. (2019). Design and Fabrication of an Autonomous FireFighting Robot with Obstacle detection And Fire Detection Using Arduino. *International Research Journal of Engineering and Technology (IRJET)*, 331.

Archana, B., & Suma, K. (2019). Design and Fabrication of an Autonomous Fire Fighting Robot with Obstacle detection And Fire Detection Using Arduino. *International Research Journal of Engineering and Technology (IRJET)*, 331 - 333.

Asimov, I. (1964). *The Rest of the Robots.* Doubleday.

Day, C.-P. (2018). *Robotics in Industry —Their Role in Intelligent Manufacturing.* Foxconn Technology Group, Shenzhen 518110, China: Elsevier LT.

Eka Cahya Prima, S. S. (2016). Automatic Water Tank Filling System Controlled using Arduino based Sensor for Home Application. *Engineering Physics International Conference, EPIC 2016.* Pendidikan, Indonesia.

Harik, E., & A, K. (2018). Combining Hector SLAM and Artificial Potential Field for Autonomous Navigation Inside a Greenhouse. *Robotics*, 22.

Hasimi, M. S., W., Z., Shafie, S., & Marhaban, H. (2010). Fire Fighting Robot. *Department of Electrical and Electronic, Universiti Putra Malaysia*.

Hasimi, M., Zuha, W., Suhaidi, S., & Hamiruce, M. (2010). Fire Fighting Robot. *Department of Electrical and Electronic, Universiti Putra Malaysia*, 1.

Hyung, H., Ahn, B., Cruz, B., & Lee, D. (2016). Analysis of android robot lip-sync factors affecting communication. *11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 441-442.

Koorsen Fire & Security. (2017, December 07). *WHAT ARE THE DIFFERENT TYPES OF FIRE EXTINGUISHERS & THEIR USES*. Retrieved from Koorsen Fire Blog: https://blog.koorsen.com/what-are-the-different-types-of-fire-extinguishers-their-uses

Lentile, L., Morgan, P., Hudak, A., Bobbitt, M., Lewis, S., Smith, A., & P.R., R. (2007). Post-fire burn severity and vegetation response following eight large wildfires across the western United States. *Fire Ecology*, 91-108.

M.H. Muhammad Sidik, S. C. (2017). Volume Measuring System Using Arduino for Automatic Liquid Filling Machine . *International Journal of Applied Engineering Research , 12*(24), 14505-14509.

Mohd, A., Nor, S., Yusof, M., & Azavitra, Z. (2019). Development of Fire Fighting Robot (QRob). *International Journal of Advanced Computer Science and Applications (IJACSA)* , 142-147.

Naomi, K., Barai, R., Irawan, A., & Daud, M. (2014). Historical and Modern Perspective of Walking Robots in Hydraulically Actuated Hexapod Robots. *Springer*, 19-40.

National Careers Service (UK). (2017, September 13). *Firefighter - Job Profile*. Retrieved from https://nationalcareers.service.gov.uk/job-profiles/firefighter

National Wildfire Coordinating Group. (2009, November 18). *Glossary of Wildland Fire Terminology.* Retrieved from National Wildfire Coordinating Group: http://www.nwcg.gov/pms/pubs/glossary/pms205.pdf

Sheets, C., & Sutphin, J. (2019). *Trinity College Fire Fighting Robot Competition.* Hartford, Connecticut: Trinity College International Robot Contest.

Wallén, J. (2008). *Estimation-based iterative learning control.* Department of Electrical Engineering, Linköping University.

APPENDIX

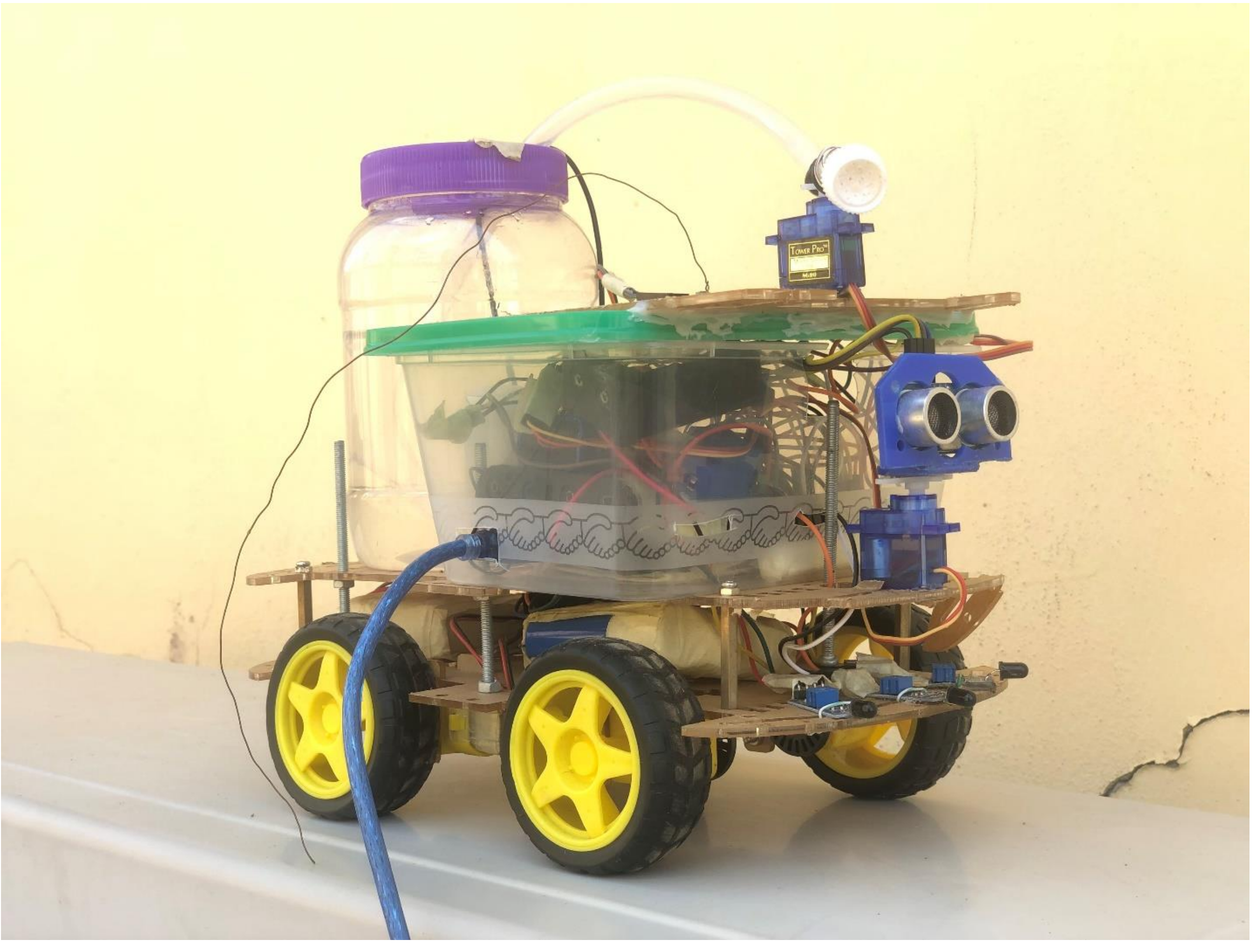

FIGURE 13: ROBOT FRONT VIEW

FIGURE 14: ROBOT BACK VIEW