COVER PAGE

DESIGN OF A SMART WIRELESS FIRE-FIGHTING SYSTEM FOR BUILDINGS

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PROJECT SUPERVISOR: ENGR. DR. E. M. ETUK

FEBRUARY, 2025.

CERTIFICATION

This is to certify that this project work DESIGN OF A SMART WIRELESS FIRE-FIGHTING SYSTEM FOR BUILDINGS was carried out by EMMANUEL OSAGIE with matriculation number ENG1905880 in the Department of Production Engineering, Faculty of Engineering, University of Benin, Benin City in partial fulfillment of the requirement for the Award of Bachelor of Engineering (BEng.) in Production Engineering.

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DR (MRS.) I. C. ILUOBE **DATE**

(PROJECT CO-ORDINATOR)

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(HEAD OF DEPARTMENT)

DEDICATION

I dedicate this project to God almighty, my family and colleagues who have supported and inspired me throughout this journey. Your guidance, encouragement and collaboration have made this work possible and I am grateful for the opportunity to share it with you.

ACKNOWLEDGEMENT

I would like to acknowledge the support and contributions of my project team and supervisor as well as the valuable feedback from peers in making this project possible.

I would like to express my deepest appreciation to all those who provided me the possibility to complete this report. A special gratitude I give to my final year project supervisor, Engr. Dr. Etuk whose contribution in stimulating suggestions and encouragement, helped me to coordinate my project especially in writing this report.

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ABSTRACT

Fire outbreaks in residential, commercial, and industrial buildings continue to pose significant threats to lives, property, and the environment, largely due to delayed detection and inefficient response mechanisms. Traditional fire-fighting systems often rely on manual operation or wired infrastructure, which may limit their effectiveness during emergencies. This study presents the design and development of a smart wireless fire-fighting system aimed at improving early fire detection, rapid alerting, and efficient fire suppression within building environments.

The proposed system integrates temperature sensors, smoke sensors, and flame sensors with a microcontroller unit to continuously monitor environmental conditions in real time. Wireless communication technology is employed to transmit data and alerts to a central control unit and authorized mobile devices, enabling remote monitoring and timely response. Upon detecting abnormal conditions indicative of fire, the system automatically triggers alarms and activates fire-suppression mechanisms such as water sprinklers while simultaneously notifying building occupants and emergency responders. The design emphasizes low power consumption, scalability, and reliability, making it suitable for both small- and large-scale building applications.

Simulation and prototype testing results demonstrate that the system is capable of accurately detecting fire incidents at an early stage and responding within a short time frame, thereby reducing potential damage and enhancing occupant safety. The wireless architecture eliminates complex wiring requirements, reduces installation costs, and allows easy expansion and maintenance. Overall, the smart wireless fire-fighting system provides an effective, intelligent, and cost-efficient solution for modern building fire safety management and contributes to the advancement of smart building technologies.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Fire protection is an essential field that focuses on minimizing the harmful effects of fires through preventive and active measures. Active fire protection refers to methods aimed at stopping the spread of fire by utilizing various fire protection devices, such as fire sprinklers, extinguishers, and alarms (Dare *et al.*, 2022). These devices play an important role in safeguarding people and property from the dangers of fire, a concern that demands significant attention. Fire protection devices are particularly important in mitigating fire damage before the fire brigade's arrival, thus preventing the escalation of the fire. The most common forms of active fire protection are fire sprinklers (which automatically activate to suppress flames) and fire extinguishers (which can be manually used to combat smaller fires) (Yatim *et al.*, 2020). In developed areas, firefighting services are readily available, but early detection and action are key in reducing the risks associated with fires.

Fire alarms are important in fire protection, with smoke and heat detectors being the most prevalent types used in homes, offices, and other buildings (Kodur *et al.*, 2020). The choice between these detectors depends on the environment and the level of response required. Heat detectors, for instance, are traditional devices that activate when the temperature rises to a certain level. While heat detectors are beneficial in environments where smoke detectors are unsuitable, they tend to have slower response times due to the gradual increase in temperature. Smoke detectors, on the other hand, offer faster detection by identifying the presence of smoke, which usually occurs before a fire fully ignites. Smoke detectors are therefore considered more efficient in early fire detection and are classified into three main types: ionization, photoelectric, and combination detectors, each offering unique advantages depending on the setting (Khan *et al.*, 2022).

In many parts of the world, including developing countries and small-scale environments, fire safety is often compromised by poor infrastructure and limited access to fire protection devices. In China, for example, 94% of fire-related incidents have occurred in micro- and small-scale sites such as rural areas, shantytowns, and buildings with limited fire prevention measures (Shi and Songlin, 2020). These sites, which often lack adequate fire detection systems, experience higher fire-related death rates. Factors contributing to this problem include inadequate safety awareness among property owners and the poor quality of fire detection products, such as battery-powered smoke alarms that lack networking capabilities and fail to provide warnings when their batteries are low or when the device malfunctions.

Also, wired fire detection systems, while effective, are costly to install and maintain in smaller sites (Varshini, 2024). This shows the need for affordable and reliable wireless fire protection systems that can offer early detection and warnings, ensuring better indoor safety. Wireless systems, with long standby times, interconnected functionality, and active alarms, can be vital in providing high-reliability fire warnings in environments where traditional systems are impractical.

1.2 Statement of the Problem

In Nigeria, the frequent occurrence of fire outbreaks resulting in significant loss of lives and property points to the urgent need for more effective fire safety measures (Ebekozien *et al.*, 2021). Residential buildings are particularly vulnerable to fire disasters, largely due to a lack of adequate fire safety awareness among the populace. Fire safety practices have not yet been properly integrated in Nigerian society, leading to frequent and often deadly fires (Oloke *et al.*, 2021). Many homes in Nigeria lack basic fire detection systems, such as smoke alarms and fire extinguishers, which could help prevent or mitigate fire outbreaks at their early stages. The situation is even more concerning as high-rise buildings continue to emerge across the country, where fire safety concerns are magnified due to the challenges in evacuating occupants and controlling fires in taller structures (Nimlyat *et al.*, 2017).

Oluwunmi *et al.* (2023) assessed fire safety practices in public buildings in western Nigeria and found that essential fire safety equipment was either unavailable or non-functional. In many cases, occupants were unaware of the existence of fire safety tools or how to use them, further exacerbating the risk.

Implementing smart, wireless fire detection systems could significantly improve fire safety, especially in residential areas where early detection and response are crucial in minimizing damage and saving lives.

1.3 Aim and Objectives of the Study

1.3.1 Aim of the Study

The aim of this study is to design and implement a smart wireless fire-fighting system that detects fire or smoke in real-time, automatically activates a water sprinkler to suppress the fire, and sends wireless alerts to ensure prompt response, thereby enhancing fire safety in residential and commercial buildings.

1.3.2 Objectives of the Study

To achieve the aim above, the following objectives were pursued:

i. To design a smart fire detection system that uses sensors to detect the presence of smoke or fire in its early stages.
ii. To implement an automatic water sprinkler system that is activated immediately after the detection of smoke or fire to control and suppress the flames.
iii. To integrate wireless communication technology into the system to send real-time alerts to users or a control center when a fire is detected.
iv. To evaluate the performance and reliability of the system in detecting fires and responding promptly through automated sprinkling and alert notifications.

1.4 Significance of the Study

This study is significant as it aims to provide a low-cost, efficient, and responsive fire alarm system that enhances fire safety, particularly in residential and commercial buildings. In many areas, especially in developing regions like Nigeria, fire safety infrastructure is either inadequate or too expensive for widespread adoption. Designing a smart wireless fire-fighting system that is both affordable and effective help addresses this gap in fire protection. The ability of the system to detect fires at an early stage, activate an automatic sprinkler system, and send real-time alerts ensures faster response times, reducing the risk of severe property damage and loss of life.

1.5 Scope of the Study

The scope of this study covers the design, implementation, and evaluation of a smart wireless fire- fighting system using Internet of Things (IoT) technology. The system will be developed to detect fire or smoke in residential and commercial buildings, automatically activate a water sprinkler system, and send real-time alerts via wireless communication to notify users or emergency services. The study will explore the use of IoT-based sensors for detecting fire hazards, ensuring early detection and prompt response. It will also focus on integrating cloud-based communication for remote monitoring, enhancing the usability and reliability of the system. The study will primarily address the technical design and performance assessment of the system within controlled environments, evaluating its efficiency, affordability, and scalability for wider adoption in fire- prone areas.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction to Fire Protection and Safety

Fire protection and safety involve a comprehensive set of measures and practices aimed at reducing the devastating effects of fire outbreaks (Amasi, 2021). These efforts are primarily focused on protecting lives and properties by minimizing the risk of fires and ensuring prompt action when they occur. Active fire protection plays a crucial role in stopping the spread of fire through the use of specialized devices such as fire alarms, sprinklers, and extinguishers. These tools help contain fire outbreaks and provide immediate response before the arrival of firefighters. The need for effective fire protection systems has become increasingly important, particularly in densely populated urban areas where the risk of fire outbreaks can lead to catastrophic losses (Onwumere *et al.*, 2022).

The practice of fire safety goes beyond simply installing protective devices; it involves a well-coordinated management system that includes regular maintenance and inspection. According to international fire safety codes, systems such as fire alarms, sprinklers, and standpipes must be kept in operable condition at all times to ensure they function effectively in the event of an emergency (Jacoby *et al.*, 2016). Regular inspections not only guarantee that fire protection devices are in working order but also increase the safety of first responders, who often arrive at the scene of a fire to contain the situation. In markets and other public spaces, annual fire inspections are particularly important as they help mitigate risks by identifying potential hazards before they escalate into full-blown disasters.

Fire safety is achieved through a combination of physical measures, such as the installation of fire- resistant materials, and management strategies, including staff training and emergency response planning (Muhamad Salleh *et al.*, 2020). In addition to the physical structure of a building, fire safety also takes into account human behavior during a fire and how well-prepared occupants are to evacuate or respond to the situation. The comprehensive approach to fire safety includes escape routes, fire drills, and ensuring that building materials meet the required standards for fire resistance (Kodur *et al.,* 2020). All these factors work together to minimize the spread of fire and reduce the likelihood of severe damage or loss of life.

Despite these advancements in fire safety practices, many buildings, particularly in developing regions, still fail to meet basic fire safety standards. Poor compliance with fire safety regulations can result in uncontrollable fire outbreaks, which lead to significant property damage and loss of lives. The International Fire Code emphasizes the need for continuous monitoring and maintenance of fire protection systems to prevent these situations. Unfortunately, in areas with limited resources, such as informal settlements or underdeveloped urban neighborhoods, fire outbreaks are often exacerbated by a lack of infrastructure, including water supply systems and well- equipped firefighting services.

In places where resources are limited, firefighting can be a challenge. Trained firefighters rely on water supply systems, such as mains and hydrants, to extinguish fires, but in some cases, they may have to use specialized firefighting foam, depending on the type of fire. The construction of buildings with minimal compliance to fire safety standards adds to the complexity of fire management, especially in growing urban areas where rapid development does not always account for fire safety measures. Firefighters, in these cases, must deal with fires that are difficult to control, resulting in greater damage and potential loss of life.

The importance of risk analysis in fire protection cannot be overemphasized. Risk analysis helps in identifying potential hazards within a building, assessing the likelihood of fire outbreaks, and determining the necessary measures to minimize those risks.

2.2 Type of Fire Detection Systems

Fire detection systems play a critical role in protecting lives and property by providing early warning in case of fire outbreaks. There are various types of fire detection systems, each suited to different environments and fire risks. These systems can be categorized into heat detectors, smoke or gas detectors, flame detectors, and semiconductor gas detectors, each utilizing different technologies to detect fires effectively.

2.3 Heat/Thermal Detectors

Heat or thermal detectors are among the earliest forms of fire detection systems, dating back to the 1800s. These detectors are triggered when the temperature in a room reaches a predefined threshold or when there is an abnormal rise in temperature. Heat detectors are known for their reliability, low cost, and ease of maintenance. However, they are slower in response compared to other detectors, as they activate only after the fire has significantly progressed. This delay in activation can result in considerable damage before the fire is detected, limiting the use of heat detectors in environments where rapid response is critical.

2.4 Smoke or Gas Detectors

Smoke or gas detectors, developed in the 1970s and 1980s, are more advanced and can detect fires in their early stages. These detectors come in various types, such as photoelectric, ionization, and air sampling detectors. Photoelectric detectors work by detecting smoke particles that scatter light into a photodiode, making them highly effective in detecting smoldering fires, such as those caused by electrical faults. On the other hand, ionization detectors use radioactive elements like americium-241 to ionize the air, detecting rapid flaming fires more efficiently. Although ionization detectors are cheaper, they pose environmental and safety risks due to their radioactive components, and their use has been banned in some countries. Air sampling detectors are highly sensitive systems designed to detect very fine smoke particles, making them ideal for high-value and sensitive environments like server rooms, art galleries, and archives. However, their complexity and cost limit their application to specialized areas.

2.5 Flame Detectors

Flame detectors are highly sophisticated fire detection systems that respond to the presence of flames by sensing radiation in specific light wavelengths, such as ultraviolet (UV) and infrared (IR) ranges. UV detectors can detect fires within milliseconds by recognizing the UV radiation emitted from flames, though they may require time delays to avoid false alarms from sources like lightning or welding. IR detectors are commonly used in high-risk environments, including refineries, mines, and aircraft maintenance facilities, due to their accuracy in detecting open flames. There are also combination flame detectors that use both UV and IR technologies to improve reliability and reduce false alarms. While flame detectors offer precise and fast detection, their cost and complexity make them suitable for industrial and high-risk settings.

2.6 Semiconductor Gas Detectors

Semiconductor gas detectors work by detecting chemical reactions between gases released in a fire and the semiconductor materials in the sensor, such as tin dioxide or tungsten oxide. These detectors are small, inexpensive, and easy to install, making them highly practical for detecting fires involving combustible gases like methane, propane, or carbon monoxide. Due to their reliability and versatility, semiconductor gas detectors are widely used in environments where gas leaks or explosions pose significant risks.

2.7 Types of Sprinkler Systems

Sprinkler systems are an essential component of modern fire safety protocols, designed to control or suppress fires before they escalate. Since their invention in the late 19th century, they have evolved into various forms, each tailored to different fire hazards and environmental conditions. The primary objective of any sprinkler system is to reduce fire damage until firefighters arrive. Below is a detailed discussion of the different types of sprinkler systems, focusing on their specific features and applications.

2.8 Wet Pipe System

The wet pipe sprinkler system is the most common and simplest type of fire protection system. It consists of a network of pipes filled with water, which is always under pressure. When a fire triggers the system, heat-sensitive sprinklers activate, causing water to be discharged over the fire source. This system is highly effective in environments with normal ambient temperatures, as the water is ready to flow immediately once the sprinklers are activated.

Each sprinkler head in a wet pipe system operates independently, meaning only the sprinkler closest to the fire will discharge water. This prevents unnecessary water damage to areas that are not affected by the fire. The activation mechanism involves either a glass bulb or a fusible link that reacts to heat, allowing water to flow through the sprinkler head.

One of the primary advantages of wet pipe systems is their reliability, ease of maintenance, and quick response. However, they are unsuitable for colder environments as the water in the pipes could freeze, causing pipe bursts and system failure.

2.9 Dry Pipe System

The dry pipe sprinkler system is designed for environments where freezing temperatures are a concern, such as unheated warehouses or cold storage facilities. Unlike wet pipe systems, the pipes in a dry system are filled with pressurized air or nitrogen rather than water. When the sprinkler head is activated by heat, the air is released from the pipes, allowing water to flow into the system and be discharged through the sprinkler.

While dry pipe systems are useful in preventing freeze-related issues, they are slower to respond compared to wet pipe systems. The delay occurs because the air must be expelled from the pipes before the water can flow. Despite this delay, dry pipe systems are a popular choice in environments where freezing temperatures make wet pipe systems impractical.

2.10 Preaction System

A preaction sprinkler system combines elements of both wet and dry systems. It is typically used in environments where accidental water discharge would cause significant damage, such as in museums, data centers, or libraries. This system uses a fire detection mechanism to control the release of water into the piping. In the event of a fire, the detection system sends a signal to release water into the pipes, but the sprinklers will not discharge water until they are activated by heat. The dual activation process—first by the detection system and then by the sprinkler—ensures that water is only discharged when absolutely necessary, reducing the risk of accidental water damage. This makes preaction systems ideal for protecting valuable assets that could be harmed by water.

2.11 Deluge System

The deluge sprinkler system is similar to the dry pipe system but has open sprinklers rather than heat-sensitive ones. When the fire detection system senses a fire, it activates a deluge valve, allowing water to flow from all the sprinklers simultaneously. This results in a large volume of water being discharged over the entire area, making it ideal for high-hazard environments such as chemical plants, aircraft hangars, and refineries.

Deluge systems are particularly effective in suppressing fast-spreading fires or protecting areas with highly combustible materials. However, they can cause extensive water damage due to the wide distribution of water, which is why they are typically reserved for high-risk industrial applications.

2.12 Foam Water System

Foam water sprinkler systems are designed for special hazard environments, particularly those that involve flammable liquids. This system discharges a mixture of water and foam concentrate, creating a foam spray that covers the fire. The foam helps to smother the flames and cool the fire, making it more effective than water alone in combating flammable liquid fires.

These systems are commonly found in facilities such as airport hangars, fuel storage areas, and chemical plants. The foam-water combination ensures that fires fueled by volatile substances are quickly controlled, minimizing the risk of explosions or further spread.

2.13 Water Spray System

The water spray system is similar in function to a deluge system but is designed to protect specific hazards that are uniquely configured, such as electrical transformers or industrial machinery Instead of covering a broad area, the water spray system targets three-dimensional objects or equipment with specific spray patterns. The system uses nozzles rather than traditional sprinkler heads, and the spray patterns can be customized to match the shape of the equipment being protected.

Water spray systems are often used in areas where direct, targeted cooling of hazardous equipment is necessary, such as in power plants or fuel storage facilities. This system helps prevent equipment failure or explosion by keeping temperatures under control.

2.14 Water Mist System

The water mist system is a unique type of sprinkler system that uses very fine water droplets to control or suppress fires. Water mist systems are often used in areas where water damage is a concern or where water supplies are limited. The mist is created by forcing water through specialized nozzles at high pressure, resulting in droplets smaller than 1000 microns.

Because of the smaller droplet size, water mist systems cool the fire more efficiently than traditional sprinklers by absorbing more heat and converting the water to steam faster. This rapid cooling effect helps reduce the temperature of the flames and limits fire spread. Water mist systems are often used in places like historic buildings, ships, or data centers, where minimal water damage is desired.

2.15 Internet of Things (IoT) in Fire Safety

The Internet of Things (IoT) represents a transformative advancement in technology that integrates physical devices with software, sensors, and communication facilities, enabling the collection, exchange, and processing of data. With the evolution of IoT, various industries have been able to implement smarter solutions to improve efficiency, safety, and responsiveness. One critical area where IoT has shown immense potential is fire safety. In fire safety, IoT systems help to detect, monitor, and respond to fire incidents in real-time, significantly improving response times and mitigating the risks associated with fires. This essay discusses the application of IoT in fire safety, focusing on its ability to provide affordable, effective, and responsive solutions to fire hazards.

2.15.1 The Role of IoT in Fire Detection

Fire detection is the first and most crucial stage in preventing and managing fire outbreaks. Traditional fire alarm systems rely on heat and smoke detectors to trigger alarms. However, these systems often suffer from slow detection rates and false alarms, particularly when not maintained properly. With the advent of IoT in fire safety, more sophisticated and responsive fire detection systems have been developed. These systems use a combination of sensors—such as temperature, smoke, and flame sensors—connected to an IoT network. When these sensors detect unusual heat or smoke patterns, they send real-time data to a central control system or directly to a remote user via a smartphone application.

The advantage of using IoT-based fire detection systems is their ability to provide accurate, real-time alerts even when the property is unoccupied, ensuring that fire incidents are identified at the earliest stages. Furthermore, by incorporating advanced sensors and communication protocols, IoT-based systems minimize false alarms and can differentiate between actual fires and non- threatening events like cooking smoke or steam.

2.15.2 IoT in Fire Response and Sprinkler Systems

In addition to improving fire detection, IoT technology enhances fire response mechanisms through automated fire suppression systems, such as sprinklers. Traditionally, sprinklers activate based on the heat in a room, but IoT allows for a more intelligent and coordinated response. By analyzing the data collected from various sensors in the building, IoT-enabled fire safety systems can determine the exact location of the fire and activate the sprinklers in that specific area. This targeted approach reduces water damage to non-affected areas and increases the efficiency of fire suppression. For instance, if a fire is detected in one part of a building, IoT-based systems can trigger sprinklers only in that zone, while also alerting the relevant authorities or building occupants. Furthermore, IoT systems can monitor the effectiveness of the sprinkler system in real-time, ensuring that the water pressure and spray are sufficient to contain or extinguish the fire.

2.15.3 Remote Monitoring and Control through IoT

One of the key benefits of IoT in fire safety is the ability to monitor fire safety systems remotely. In the past, building owners and safety personnel had to be on-site to manage fire safety protocols. However, IoT has revolutionized this process by enabling real-time monitoring from virtually any location. Fire safety systems connected to the IoT can send alerts to smartphones, tablets, or computers, allowing users to access critical information about fire incidents remotely. For example, in the case of a fire in an industrial plant located far from the monitoring center, the IoT system would alert the relevant personnel instantly, allowing them to take immediate action such as shutting down equipment, activating emergency protocols, or even deploying fire suppression systems, all from a remote location. This capability is particularly valuable in industries with large plants or facilities in remote areas where immediate human response is not feasible.

2.15.4 Data Analytics and Predictive Maintenance

IoT's role in fire safety extends beyond just fire detection and suppression; it also contributes to predictive maintenance and data analytics. IoT systems continuously gather data from sensors, including temperature readings, humidity levels, and smoke detector performance. By analyzing this data over time, IoT platforms can detect patterns that may indicate a potential fire hazard, such as a gradual increase in temperature in a specific area of a building.

Predictive maintenance can be carried out based on this data, ensuring that fire safety systems are always in optimal working condition. For instance, if a smoke detector or sprinkler system begins to malfunction or show signs of wear, the IoT system can alert maintenance personnel before a serious issue arises. This proactive approach minimizes the risk of system failure during a fire emergency and ensures that all fire safety equipment is functioning efficiently.

2.15.5 Smart Buildings and Autonomous IoT Systems

The concept of smart buildings, where various IoT devices and systems work in conjunction to optimize building operations, is closely linked to IoT in fire safety. In smart buildings, fire safety systems are integrated with other building management systems such as heating, ventilation, and air conditioning (HVAC), security, and lighting. This integration allows for a more comprehensive approach to fire safety. For example, if a fire is detected in a smart building, the IoT system can automatically shut down the HVAC system to prevent smoke from spreading to other parts of the building. Additionally, the system can unlock doors or turn on emergency lighting to facilitate the safe evacuation of occupants. Autonomous inter-appliance communication is another significant aspect of IoT in fire safety, where devices can communicate with each other without human intervention, ensuring a coordinated response to fire emergencies.

2.15.6 Challenges and Future Prospects of IoT in Fire Safety

Despite the numerous advantages of IoT in fire safety, there are still some challenges that need to be addressed. One of the primary concerns is the cost of implementing IoT systems, particularly in large buildings or industrial facilities. Although IoT technology has become more affordable over the years, the initial setup costs may still be prohibitive for some businesses.

Another challenge is the potential for cybersecurity threats. As IoT systems rely on internet connectivity, they are vulnerable to hacking or data breaches, which could compromise the safety of the building.

However, the future prospects for IoT in fire safety are promising. As technology continues to advance, IoT systems will become more affordable and accessible to a broader range of users. Furthermore, innovations in artificial intelligence (AI) and machine learning will enhance the capabilities of IoT fire safety systems, allowing for even faster and more accurate fire detection and response. With AI integration, IoT systems will be able to learn from past fire incidents and improve their algorithms, reducing false alarms and improving detection rates.

2.16 Review of Existing Smart Fire-Fighting Systems and Their Effectiveness

Smart fire-fighting systems are a technological leap in the prevention, detection, and suppression of fire hazards. These systems integrate various advanced technologies such as Internet of Things (IoT), sensors, and robotics to enhance their efficiency and responsiveness compared to traditional fire-fighting mechanisms.

One of the central innovations in smart fire systems is the integration of mobile-sensor fire prevention systems, which rely heavily on IoT technologies. These systems, such as the one described by Rosas *et al.* (2017), utilize a combination of temperature sensors, fire detectors, and smoke detectors to monitor buildings continuously. Upon detecting abnormal temperature fluctuations, the system triggers alarms and sends notifications to building occupants via mobile devices, enhancing the evacuation process. The ability of such systems to predict and prevent fires based on subtle environmental changes has significantly reduced response times and loss of property. This early warning capability is crucial in mitigating fire damage, particularly in residential and commercial buildings where rapid response can mean the difference between containment and disaster.

Similarly, IoT-based fire alarm systems have been developed using open-source computing platforms like Arduino, as demonstrated in Dumlao (2016) prototype. This system is designed to interface with personal computers for fire alarm communication and control, and is relatively low- cost and accessible, making it ideal for domestic use. It provides an early warning system that can save lives by ensuring users are alerted well before a fire spreads. The Arduino platform also allows for customization and scalability, making it adaptable for various building sizes and configurations.

Home-based fire monitoring systems, such as the one proposed by Suresh *et al.* (2016), also rely on Arduino technology but are tailored for household use. These systems focus on minimizing property damage and saving lives through early detection. They offer constant fire monitoring, alerting homeowners to potential fire outbreaks and triggering alarms that can prevent fires from escalating. Such systems are particularly beneficial in areas where fire services may not be readily available or in rural settings where emergency response times are longer.

Another notable system is the controlled robot for fire detection and extinguishment developed by Taha and Marhoon (2018). This robotic system detects fires in confined spaces using sensors and a wireless camera. The robot's ability to locate fires in otherwise inaccessible areas enhances fire- fighting efforts, particularly in industrial settings. The integration of a wireless camera allows the system to detect fires from a distance, reducing the risk to human firefighters. However, one limitation of this system is its inability to operate effectively outside of predefined areas, a challenge that underscores the need for further development in enhancing the mobility and coverage of such robots.

Similarly, Azmil *et al.* (2015) explored wireless fire detection systems that use microcontrollers and sensors to monitor fires in real time. These systems typically include a combination of buzzers, smoke sensors, and cameras that transmit data to a central monitoring station. The real-time monitoring capability ensures that firefighters or emergency responders receive immediate updates about fire outbreaks, enabling faster and more coordinated responses. Moreover, the integration of wireless technology improves system reliability by eliminating the need for physical connections, which can be damaged during a fire.

For older buildings, which are often not equipped with modern fire safety systems, the low-cost R-type fire alarm system proposed by Chen *et al*. (2016) provides a viable solution. This system uses an Arduino Uno microcontroller to continuously monitor for fire outbreaks, resetting itself to a monitoring mode when no fire is detected. The affordability and simplicity of this system make it especially useful for retrofitting old structures, which are more susceptible to fire hazards due to outdated infrastructure. Its ability to alert occupants in the event of a fire ensures that residents of older buildings are not left vulnerable to fire risks.

The effectiveness of smart fire systems can be significantly enhanced by incorporating IoT technology, as highlighted by the fire safety and alert system developed by Perilla *et al.* (2018). By using sensors to detect temperature changes, gas leaks, and smoke, IoT-based systems offer more comprehensive fire detection capabilities. These systems can detect fire hazards at an earlier stage compared to traditional alarms, which rely primarily on the presence of flames or dense smoke. Furthermore, IoT integration allows for real-time updates to be sent to users' devices, providing critical information for both escape and fire suppression efforts.

The vision-based automatic fire protection system discussed by Salim *et al.*, (2021) exemplifies how digital imaging and control systems can be used to propose new solutions for fire suppression. This system employs a sprinkler system that can be automatically activated in response to visual cues such as the appearance of smoke or flames. By using image recognition technology, the system can accurately detect fires and activate suppression mechanisms faster than traditional fire alarms that rely solely on smoke or heat detection. The use of digital imaging also allows for more precise targeting of fire hotspots, potentially reducing water waste and minimizing damage to the property.

Robotics have also played a vital role in enhancing the capabilities of modern fire-fighting systems. Autonomous fire-fighting robots like the one described by Abad *et al.* (2019) are capable of detecting and extinguishing fires without human intervention. These robots use advanced sensors to locate fires within a room and can respond by spraying water or other extinguishing agents in the affected area. Their ability to operate in hazardous environments makes them invaluable in situations where human firefighters would be at significant risk, such as in chemical fires or explosions. The effectiveness of these systems lies in their autonomy and precision, which ensure that fires are dealt with swiftly and accurately.

In addition to robotic systems, advancements in fire suppression mechanisms, such as the water mist fire suppression system described by Mawhinney and Back (2016), have provided new methods for containing fires. This system uses water mist to cool the flames and limit the spread of fire while reducing water usage compared to traditional sprinklers. Its efficiency in containing fires in confined spaces has made it an ideal solution for industrial environments and high-risk areas.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

The materials requirements for the project include the followings;

i. Adruino software
ii. Heat/fire detection sensor.
iii. DC mechanical drivers
iv. 12V solar Batteries
v. Water pump
vi. Water reservoir
vii. Pressure hose
viii. Stainless steel sheets

3.2 Methods

The steps for the development of the automated fire extinguishing machine are detailed as follow;

i. Conceptual design
ii. Simulation using relevant computer software such Adruino and solid work
iii. Material sourcing for the fabrication of the proof of concept.
iv. Fabrication of the proof of concept using workshop techniques
v. Testing and evaluation of the proof of concept.

3.2.1 Conceptual frame work of the design

The automated fire extinguisher design operates in strategic electromechanical steps shown in

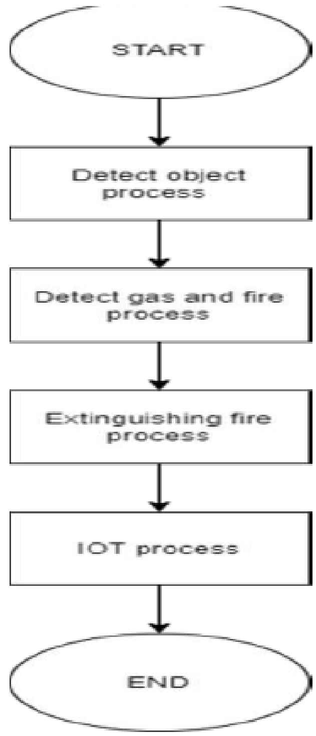

Figure 3.1 Automated Fire Extinguisher Operational Design

3.3 Detail design

3.3.1 Design variables of the proposed fire extinguishing machine;

i. The nature of and level of fire.

ii. The amount and nature of extinguisher fluid required

iii. Flow rate of the fluid

iv. Velocity of water flow in pipe

v. Size (volume) of the water holder

vi. Height of the discharge (hydraulic head)

vii. Pipe sizing

viii. Head losses

ix. The hydraulic pump rating

x. Physical attributes (weight, dimensions) of the machine.

3.3.2 Input data

The nature of fire: Class A type fire which is common with natural composites such as wood and paper. These type of fire can be extinguished with water.

The fire is expected to be small scale fires.

i. Amount of water required in the extinguisher reservoir.

The assumption is made to have amount of water equal to 5 litters of water, which is an equivalent of a 6kg conventional hand held liquid extinguisher.

ii. Flow rate of the water into out of the reservoir during extinguishing operation

In 1 hour = $\frac{3600}{5}$ x (0.0005)m^3 = 0.36m^3 of water is expected to be drawn from the pump.

Flow rate = 0.36m^3/3600s = 0.0001m^3/s

iii. Velocity of water flow in the hose

Let V = Water flow velocity (m/h or cm/sec)

But Q = flow rate = A x V (3.1)

Where A = area of hose = πr^2

r = radius of pipe

If we select a range of available diameter of hose, a range of flow velocities is possible as shown in Table 3.1

Table 3.1 Hose size and associated flow velocity

Flow rate Q (m^3/s	Pipe dia. (cm)	Area of pipe(m^3)	Velocity of flow (m/s)
0.0001	1	$0.7855x10^{-4}$	1.27
0.0001	1.5	$1.767x10^{-4}$	0.57
0.0001	2	$3.142x10^{-4}$	0.32
0.0001	3	$7.070x10^{-4}$	0.14

From Table 3.1 it follows that higher fluid flow velocity is achieved as the pipe diameter decreases.

iv. The height of the discharge (hydraulic head)

The Hydraulic head or piezometric head is a specific measurement of liquid pressure above a geodetic datum it is given as

$$h = \Psi + z \quad (3.2)$$

Where:

h = the hydraulic head (Length in m or ft), also known as the piezometric head.

Ψ = the pressure head, in terms of the elevation difference of the water column relative to the piezometer bottom (Length in m or ft), and

z = the elevation at the piezometer bottom (Length in m or ft)

The pressure head can be expressed as:

$$\Psi = \frac{P}{Y} = \frac{P}{\rho g} = \quad (3.3)$$

where

P = the pressure of atmosphere (Force per unit area, often Pa or psi) =1

Y = unit of water (force per unit volume in $N \cdot m^{-3}$ or kg/cm^3) = $0.001kg/cm^3$

ρ = the density of the water (Mass per unit volume, frequently $kg \cdot m^{-3}$)

g = the gravitational acceleration (velocity change per unit time, often $m \cdot s^{-2}$)

v. Head losses

In any real moving fluid, energy is dissipated due to friction; turbulence dissipates even more energy for high Reynolds number flows. Head loss is divided into two main categories:

a. Major losses; this is associated with energy loss per length of pipe.

b. Minor losses; these are usually estimated from tables using coefficients or a simpler and less accurate reduction of minor losses to equivalent length of pipe. It is associated with bends, fittings, valves.

Older, more empirical approaches are the Hazen-Williams equation and the Prony equation.

The Hazen-Williams equation is used for calculating the head loss due to its empirical soundness

The Hazen-Williams equation when used to calculate the head loss is given as

$$S = \frac{h_f}{L} = \frac{10.67Q^{1.85}}{C^{1.85}d^{14.87}} \quad (3.4)$$

where:

S = Hydraulic slope

h_f = head loss in meters (water) over the length of pipe

L = length of pipe in meters

Q = volumetric flow rate, m^3/s (cubic meters per second)

C = pipe roughness coefficient

d = inside pipe diameter, m (meters) Table 3.2 equivalent losses in pipes and fittings

The head losses must be considered and added to the hydraulic head and the farthest internal wall from a central axis of the tank to achieve the delivering pressure (P) of the pump.

For the system the lengths of pipe and fittings and their losses are computed in Table 3.2.

Item	Length l (m)	Losses = l/L
Pipe	0.9	0.9
	1.8	0.6
Total		**1.5**
Bends	4 x 0.75	1.2
Tees	1 x 0.3	0.3
Valves	1 x 0.1	0.1
		1.6
Total losses		**3.1**

The total head the pump must have to overcome to discharge is

$H = h_L + h_D$ (3.5)

Where

h_L = head losses

h_D = dynamic losses = $\frac{kv^2}{2g}$ (3.6)

where;

v = velocity in the pipe (m/sec)

g = acceleration due to gravity (m/sec^2)

K = loss coefficient = $K_{pipe} + K_{fittings}$ (3.7)

K_{pipe} = fl/D

The flow is assumed to be a lamina since at Reynolds number below the critical value of approximately 2040 pipe flow will ultimately be laminar, hence excessive losses due to turbulence is neglected.

H = calculated head

vi. The hydraulic pump power rating**($P_{h(kw)}$)**

The pump capacity rating and selection is dependent on the total head calculated plus a factor of safety required to deliver the required pressure.

The ideal hydraulic power to drive a pump depends on

i. the mass flow rate

ii. the liquid density

iii. the differential height

and it is expressed as:

$$P_{h(kW)} = \frac{q\ \rho\ g\ h}{3.6 \times 10^6} \qquad (3.8)$$

where

$P_{h(kW)}$ = hydraulic power (kW)

q = flow capacity (m^3/s) = v/h = $0.0001m^3/s$ =

ρ = density of fluid (kg/m^3) = $1000kg/m^3$

g = gravity ($9.81\ m/s^2$)

h = differential head (m) = 10m

Fire Extinguisher Machine Sizing

This measured based on human modulo which helps accounts for eases of handling and operation. Height of machine = average height of the lower body of an average sized man beginning from the foot to the waist line. This was computed based on experimental sampling and evaluation of averages as 0.526m

Mechanical drivers or Actuators

The mechanical drivers or actuators are sets of electronic DC motors required for the moving parts of the machine such as the wheel fulcrum, wheels and base rotation. Considering uniform speed and the weight of the individual components, the torque required to drive a given component is expressed as;

T = F x d (3.9)

Where;

F = force,

d = perpendicular distance of force from point of acting.

But from first principles, F is a function of mass of the component and its acceleration. This follows that

T = Ma x d from equation (3.9).

The electrical components configuration.

The main electronic Components /Sections include the followings;

a. **Arduino Mega (the MCU)**

The Arduino Mega shown in Figure 3.2 is a microcontroller board based on the ATmega2560 microcontroller. It has 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It can be used to develop a variety of electronic devices. The Arduino Mega has a number of digital and analog input/output pins, as well as several other hardware features.

Figure 3.2 Arduino Mega (the MCU)

The specific specs of the Arduino Mega are as follows:

Microcontroller: ATmega2560

Operating Voltage: 5V

Input Voltage: 7-12V

Digital I/O Pins: 54 (of which 14 can be used as PWM outputs)

Analog Input Pins: 16

DC Current per I/O Pin: 40 mA

DC Current for 3.3V Pin: 50 mA

Flash Memory: 256 KB of which 8 KB used by bootloader

SRAM: 8 KB

EEPROM: 4 KB

Clock Speed: 16 MHz

LED_BUILTIN: 13

Length: 101.52 mm

Width: 53.3 mm

Weight: 25 g

In addition to these specs, the Arduino Mega also has a number of other hardware features, including 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. These features make it easy to connect the Arduino Mega to a variety of external devices, such as sensors, actuators, and other electronic components.

b. H-bridge Section

An H-bridge is a circuit that allows a voltage to be applied across a load in either direction. This is useful for controlling motors, which can be reversed by changing the direction of the voltage applied to them. Building an H-bridge using two SPDT relays and MOSFETs is a more complex but also more efficient and reliable method compared to using just relays. The relays are used to control the direction of the current flowing through the MOSFETs, which act as switches to allow current to flow through the load in either direction. By using an H-bridge circuit built with SPDT relays and MOSFETs, you can control the direction and speed of a DC motor in contrast to using just relays which controls only speed. This can be used in a variety of applications, such as robotics, automated manufacturing, and other systems that require precise control over the direction of a DC motor.

c. The Infra-red Flame Sensor

An infrared (IR) sensor shown in Figure 3.3 is an electronic device which in its surrounding environment, measures and detects infrared radiation.

Figure 3.3 Infra-red sensor

d. Source CODE

The computer code or source code refers to the set of instructions shown in scripted form or a system of rules, written in a particular programming language. It is also the term used for the source code after it has been processed by a compiler and made ready to run on the computer (i.e., the object code).

CODE

```
#include <PS2X_lib.h>  //gamepad library for arduino

#define STOP 0        // macro for the stop state

#define CCW  1          // macro for the stop state

#define CW   2           // macro for the stop state
```

```
#define  BASE_JOINT 0       // place holder for base joint

#define  LEFT_SHOULDER 1   // place holder for left shoulder joint

#define  RIGHT_SHOULDER 2   // place holder for right shoulder joint

#define  LEFT_ELBOW 3      // place holder for left elbow  joint

#define  RIGHT_ELBOW 4      // place holder for right elbow joint

#define  LEFT_GRIPPER 5          // place holder for left gripper

#define  RIGHT_GRIPPER 6          // place holder for right gripper

#define  LEFT_WHEEL 7          // place holder for left tyre

#define  RIGHT_WHEEL 8          // place holder for right tyre


//****************************_JOINT************ MOTOR PINS DEFINITION
    ********************************

#define BASE_MOTOR_A 45

#define BASE_MOTOR_B 43

#define LEFT_SHOULDER_MOTOR_A 41

#define LEFT_SHOULDER_MOTOR_B 39

#define RIGHT_SHOULDER_MOTOR_A 37

#define RIGHT_SHOULDER_MOTOR_B 35

#define LEFT_ELBOW_MOTOR_A 33

#define LEFT_ELBOW_MOTOR_B 31

#define RIGHT_ELBOW_MOTOR_A 29

#define RIGHT_ELBOW_MOTOR_B 27
```

```
#define LEFT_WHEEL_MOTOR_A 53

#define LEFT_WHEEL_MOTOR_B 51

#define RIGHT_WHEEL_MOTOR_A 49

#define RIGHT_WHEEL_MOTOR_B 47

#define LEFT_GRIPPER_MOTOR_A 52

#define LEFT_GRIPPER_MOTOR_B 50

#define RIGHT_GRIPPER_MOTOR_A 48

#define RIGHT_GRIPPER_MOTOR_B 46

#define MOSFET 3


#define LED 16 //*********************************

GRIPPER LED***************************************

PS2X ps2x; // create PS2 Controller Class

int error = 0; // error code

byte type = 0; // variable to hold the controller type

byte vibrate = 0; // variable to hold the level of vibration

int speed =0;

const int jointA[] = {BASE_MOTOR_A,
    LEFT_SHOULDER_MOTOR_A,RIGHT_SHOULDER_MOTOR_A,
    LEFT_ELBOW_MOTOR_A, RIGHT_ELBOW_MOTOR_A,
    LEFT_GRIPPER_MOTOR_A,
    RIGHT_GRIPPER_MOTOR_A,LEFT_WHEEL_MOTOR_A,RIGHT_WHEEL_MOTOR
    _A } ; // array to hold motor positive pins
```

```
const int jointB[] = {BASE_MOTOR_B, LEFT_SHOULDER_MOTOR_B,
    RIGHT_SHOULDER_MOTOR_B,LEFT_ELBOW_MOTOR_B,RIGHT_ELBOW_MOT
    OR_B, LEFT_GRIPPER_MOTOR_B ,
    RIGHT_GRIPPER_MOTOR_B,LEFT_WHEEL_MOTOR_B,RIGHT_WHEEL_MOTOR
    _B } ; // array to hold motor negative pins

boolean ledState = true;

void setup() {

  Serial.begin(57600);

  delay(500);   //use a little delay to allow the gamepad dongle initialize

  error = ps2x.config_gamepad(13, 11, 10, 12, true, true); //setup pins and settings:
    GamePad(clock, command, attention, data, Pressures?, Rumble?) check for error

  for (int i = 0; i < 9; i++) {

    pinMode(jointA[i], OUTPUT); //set mptor pins as output

    pinMode(jointB[i], OUTPUT);

    if (ps2x.Button(PSB_PAD_RIGHT)) // if right button is pressed

    {

      Joint(LEFT_WHEEL, CW); //move wheel joint clockwise

      Joint(RIGHT_WHEEL, CW); //move wheel joint clockwise

    }

    else if (ps2x.Button(PSB_PAD_LEFT))// if left button is pressed

    {

      Joint(LEFT_WHEEL, CCW); //move wheel joint clockwise

      Joint(RIGHT_WHEEL,CCW); //move wheel joint clockwise

    }
```

```
else if (ps2x.Button(PSB_PAD_UP))// if left button is pressed

{

  Joint(LEFT_WHEEL, CCW); //move wheel joint clockwise

  Joint(RIGHT_WHEEL, CW); //move wheel joint clockwise

}

else if (ps2x.Button(PSB_PAD_DOWN))// if left button is pressed

{

  Joint(LEFT_WHEEL,  CW); //move wheel joint clockwise

  Joint(RIGHT_WHEEL,CCW); //move wheel joint clockwise

}

else //stop moving base motor
```

3.4 Bill of Engineering Materials and Evaluation

The bill of engineering materials and evaluation of the medical robot is shown in Table 3.2

Table 3.2 Bill of Engineering Materials and Evaluation of solar clothes dryer

S/N	Materials	Description	Size	Quantity	Unit cost (N)	Total cost (N)
1	Stainless steel plate	Metal		1	80000	80000
2	30A electronic speed controller			5	2900	14500
3	1400kv brushless DC motor			4	3172.5	12690
4	DC drivers	11.1v		6	11000	30000
5	Lipo Battery			1	20000	20000
6	I mar battery lipo battery charger			1	3760	3760

7	Xt60 female and male plug			10	1500	15000
8	Fa i6 transmitter			1	13320	13320
9	Fs – ia6 receiver			1	13000	13000
10	Adruino uno programmable board				25000	25000
11	Lipo battery tester			1	1200	1200
12	Miscellaneous	Lump sum			15000	10000
13	Labor	Lump sum			75000	75000
14	**Total**					

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Test

The automated fire extinguisher was deployed to extinguish test fires. The heat detection sensor was activated to detect the unusual temperature within the test location after which it sends signal to a signal alarm which notifies the human operator of existence of fire within the given radius of location of the machine. The human operator can act on the alarm signal to switch on the water pump for onward spraying of water on the direction of the fire. The fluid load carried by the machine, the time and amount of water utilized in extinguishing a specific fire were recorded. The outcome of its performance evaluation were documented as sown in Table 4.1.

4.2 Results

Table 4.1 Evaluation results of fire extinguishing machine.

Test number	Amount of water (liters)	Distance away from detected fire source (m)	Time to extinguish fire (min)	Time to discharge water (min).
1	5	0.5	1	5
2	5	0.8	1	5
3	5	1	1.2	5
4	5	1.2	1.2	5
5	5	1.5	1.5	5

The graphical representation of the outcome of the fire extinguisher machine performance is also shown in the Figure 4.1.

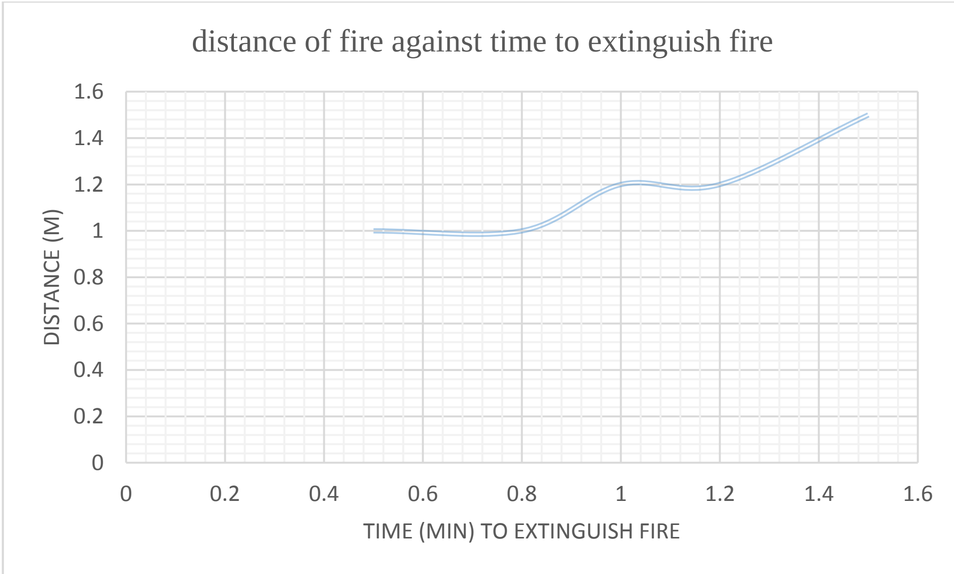

Figure 4.1 distance of fire against time to extinguish fire.

4.3 Discussion

From the test carried out it was observed that the fire extinguisher facility had the ability to be pulled through smooth and rough terrains to extinguish fires. Once within a given radius of fire or heat source, it could give off signal alarm that enables the user to initiate the pump and directs the fire hose and nozzle towards the fire. As the distance or location of the machine is farther away from the fire source within a given radius, so does it takes the machine sensor to detect the fire and so does it longer time to extinguish the fire as depicted in the Table 4.1 and Figure 4.1. This could be attributed to the pressure drop of the water flow as the distance of fire away from the hose increases. The machine will therefore need to be closer to the fire for more effective detection and concentrated extinguishing of the fire with the hose nozzle well directed at the fire and more amount of water focused on the source of fire.

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The design and production of the automated fire extinguisher machine was successful. Test results achieved showed that the it could lift a given amount of water within its designed capacity for onward discharge through its nozzle to extinguish fire. Dynamic testing of the machine also showed that it could be operated on various terrains and could detect fire within given radius of its location. The incorporation of automatic signal gadgets enabled by an Arduino platform and NodeMCU enabled the machine to detect fire automatically and give off alarm signals. The objectives of the development of automated fire detection and extinguisher system was achieved and accomplished successfully. This study has shown that the present proof of concept can enhance the safety of people and materials against fire incidents.

5.2 Recommendations

Following the conclusion of the present research work, the following recommendations were made;

i. It is recommended that subsequent incorporates the Internet of Things to the system which could enable an additional fire signal alarm of sending notification and location of the fire to the fire department and manager when fire occur. This can ease both parties of dire department and the manager for onward action.

ii. Subsequent research may increase the load carrying capacity of water and increased distance of fire detection by the machine.

iii. Automated fire extinguishing facilities like the present proof of concept are essential facilities for human and equipment safety. Their automated operation can reduce human labor, hence should be deployed commercially in work and living environments.

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