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Design and Implementation of a Robot Based on STM32 Board, Performing Tasks in Dangerous Situations

Thesis publicly defended on Jeanne 30, 2024 before the jury composed of :

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Dissertation prepared at the Research Center in Industrial Technologies "**CRTI**"

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العنوان *تصميم وتنفيذ روبوت على لوحة* **STM32**، *يؤدي المهام في المواقف الخطرة.*

ملخص *أحد المخاطر الرئيسية التي تهدد حياة رجال الإطفاء يكمن في المخاطر الكامنة في الاتصال المباشر مع النيران والبيئات الخطرة أثناء عمليات إخماد الحرائق. الهدف من هذا المشروع هو تقليل المخاطر التي تهدد حياة رجال الإطفاء أثناء التدخلات المعقدة من خلال تطوير نظام خرطوم إطفاء الحريق الذي يتم التحكم فيه عن بعد باستخدام مفاهيم روبوتات الكروم وتقنيات تجديد خطوط الأنابيب. سيسمح هذا النظام الذي يعمل بالفوهة لرجال الإطفاء بتشغيل الخرطوم عن بعد من خارج النيران، وبالتالي تقليل تعرضهم للمخاطر مع زيادة فعالية تدخل مكافحة الحرائق. من المهم إلقاء نظرة عامة على التحديات المختلفة التي يهدف هذا المشروع إلى التغلب عليها على نطاق واسع. يقوم نظام الخرطوم الذي يعمل بالفوهة بالتحكم عن بعد في خرطوم إطفاء الحريق الموجود داخل اللهب، وتوجيه المياه إلى نقطة الحريق. ويمكن تلخيص الأهداف الرئيسية لهذا المشروع على النحو التالي: زيادة سلامة رجال الإطفاء من خلال إبعادهم عن النيران، وتحسين دقة وسرعة تدخلات مكافحة الحرائق لإنقاذ الأرواح البشرية والممتلكات، والسماح بالوصول إلى الأماكن التي يصعب الوصول إليها وسهولة الانتشار، كل ذلك من خلال دمج التقنيات المتقدمة لنظام موثوق وفعال.*

الكلمات المفتاحية *الأنابيب الهيدروليكية الاتجاهية - تحسين السلامة - المراقبة البيئية - الروبوتات - روبوت مكافحة الحرائق - تكامل التقنيات المتقدمة*

Titre **CONCEPTION ET IMPLEMENTATION D'UN ROBOT SUR CARTE STM32, EFFECTUANT DES TÂCHES DANS DES SITUATIONS DANGEREUSES**

Résumé L'un des risques majeurs qui menacent la vie des pompiers réside dans les dangers inhérents au contact direct avec les flammes et les environnements dangereux lors des opérations de lutte contre l'incendie. L'objectif de ce projet est de réduire les risques qui menacent la vie des pompiers lors d'interventions complexes en développant un système de tuyaux d'incendie télécommandé utilisant les idées des robots vignerons et les technologies de rénovation de canalisations. Ce système de canalisations entraînées par buse permettra aux pompiers d'actionner le tuyau à distance depuis l'extérieur des flammes, réduisant ainsi leur contact avec les dangers tout en augmentant l'efficacité de l'intervention de lutte contre l'incendie.

Il est important de prendre un aperçu sur les différents défis que ce projet tente de surmonter, au sens large. Le système de tuyaux entraînés par une buse contrôle à distance un tuyau d'extinction d'incendie situé à l'intérieur des flammes qui dirige l'eau vers le point de l'incendie. Les principaux objectifs de ce projet peuvent être résumés comme suit : accroître la sécurité des pompiers en les gardant éloignés des flammes, améliorer la précision et la rapidité des interventions de lutte contre l'incendie pour sauver des vies humaines et des biens, permettre d'avoir accès à des espaces inaccessibles et facile à déployer, ceci par l'intégration des technologies avancées pour un système fiable et performant.

Mots-clés **Tubes directionnels hydrauliques - Amélioration de la sécurité - Surveillance environnementale - Robotique - Robot de lutte contre l'incendie - Intégration de technologies avancées.**

Title **DESIGN AND IMPLEMENTATION OF A ROBOT ON AN STM32 BOARD, PERFORMING TASKS IN DANGEROUS SITUATIONS.**

Abstract One of the major risks threatening the lives of firefighters lies in the inherent dangers of direct contact with flames and hazardous environments during fire suppression operations. The objective of this project is to reduce the risks to firefighters' lives during complex interventions by developing a remotely controlled fire hose system utilizing the concepts of vine robots and pipeline renovation technologies. This nozzle-driven system will allow firefighters to operate the hose remotely from outside the flames, thereby reducing their exposure to hazards while increasing the effectiveness of the firefighting intervention.

It is important to take an overview of the various challenges that this project aims to overcome on a broad scale. The nozzle-driven hose system remotely controls a fire extinguishing hose located inside the flames, directing water to the point of the fire. The main objectives of this project can be summarized as follows: increase the safety of firefighters by keeping them away from the flames, improve the precision and speed of firefighting interventions to save human lives and property, allow access to inaccessible spaces and easy deployment, all through the integration of advanced technologies for a reliable and efficient system.

Keywords **Hydraulic Directional Tubes - Safety Improvement - Environmental Monitoring - Robotics - Firefighting Robot - Integration of Advanced Technologies**

Summary

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The Research Center in Industrial Technologies **(Centre de Recherche en Technologies Industrielles, CRTI)** in **Cheraga Algeria** is a leading institution dedicated to the advancement of industrial technologies Its primary objectives include conducting high-level research in fields such as materials science and robotics, automation and manufacturing processes, CRTI focuses on developing innovative solutions to enhance industrial efficiency and competitiveness. A significant part of its mission is technology transfer bridging the gap between research and industry to promote the practical application of advanced technologies in Algeria's industrial sector, CRTI collaborates with national and international academic institutions, research organizations, and industrial companies, fostering a collaborative environment for scientific and technological advancements, additionally, the center is committed to training and capacity building by offering internships, workshops, and educational programs to nurture the next generation of scientists, engineers, and technologists CRTI's research areas include the development of advanced materials, robotic systems, automated processes, and sustainable by driving innovation and facilitating the adoption of cutting-edge solutions, CRTI plays a crucial role in enhancing the competitiveness of Algeria's industrial sector, contributing significantly to the country's economic growth and technological progress.

Introduction

Fire has played a crucial role in human civilization, providing warmth, enabling cooking, and fueling various industrial processes. However, when fire becomes uncontrolled, it can pose significant dangers and cause devastating consequences. The destructive power of fire is evident in historic events like the Great Fire of London in 1666, which resulted in loss of life, property damage, and environmental destruction. Despite advancements in firefighting techniques, the profession remains hazardous, with firefighters often facing life-threatening situations. One of the most perilous tasks involves directly combating active flames and exposing firefighters to extreme heat, toxic smoke, and the risk of structural collapse.

To address these challenges, this project proposes the development of an innovative firefighting robot aimed at enhancing the safety and efficiency of firefighting operations. The central concept revolves around a remotely controlled fire hose equipped with a specialized nozzle. This robotic hose can be directed towards the fire, replacing firefighters in the most dangerous parts of the task. Similar to the principles used in vine robots or pipe relining techniques, the robotic hose appears to grow as it extends forward, enabling it to reach areas that may be inaccessible or too hazardous for human firefighters.

In addition to the innovative firefighting robot with a remotely controlled fire hose, another key feature is the ability of the nozzle to change direction based on the movements of a joystick. This dynamic functionality allows the operator to have direct control over the direction in which the fire hose is aimed.

By manipulating the joystick, the operator can adjust the angle and orientation of the nozzle, enabling precise targeting of the fire. This feature is particularly valuable in firefighting scenarios where the fire may be spreading or changing direction rapidly. The operator can quickly adapt the nozzle's position to effectively combat the flames and prevent further escalation.

By utilizing this robotic firefighting technology, we can minimize the risks faced by firefighters and improve overall operational effectiveness. The remotely controlled nature of the robot allows for precise control and maneuverability, enabling targeted and efficient firefighting efforts. This innovation has the potential to revolutionize the firefighting industry and protect both the lives of firefighters and the communities they serve.

Chapter I

GENERAL

INTRODUCTION TO FIREFIGHTING

1 THE HISTORY OF FIREFIGHTING

The origins of firefighting can be traced back to the 2nd century when Ctesibius (influential-innovator-ctesibius, s.d.), an influential innovator, created a hand pump for water jets. However, this concept faded until its reinvention around AD 1500. Ancient Rome, nearly destroyed by fires, established a fire department of about 7,000 paid firefighters who not only fought fires but also enforced fire codes with corporal punishment.

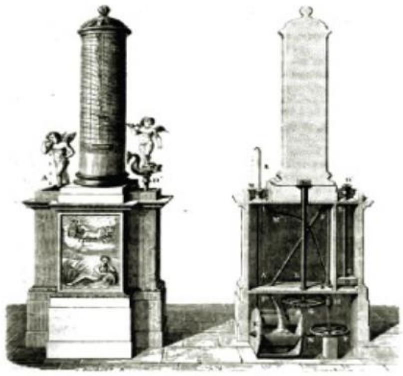

Figure 1 hand pump created by ctesibus

In the United States, fires have been a persistent issue for nearly 400 years. The first recorded structure fire occurred in 1608 in Jamestown, devastating the colony. Early American firefighting efforts relied on volunteer or private companies, sometimes competing for business. Firefighting tools included leather buckets, hooks, chains, swabs, ladders, and basic pumps.

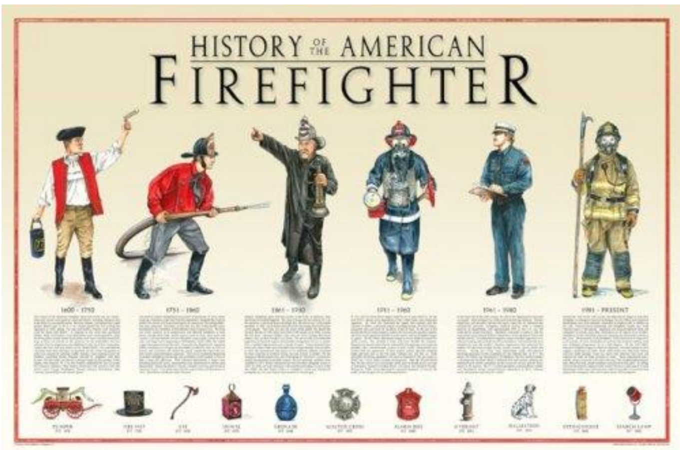

Figure 2 History of the American firefighter

Fire prevention in the US began in 1630 in Boston with regulations against wooden chimneys and thatched roofs. By 1648, New Amsterdam (now New York City) (the-history-of-firefighting, s.d.) appointed fire inspectors to enforce fire codes. The practice of bucket brigades, passing water-filled buckets hand-to-hand, was common until the advent of hand pumpers and later, steam-powered engines.

Figure 3 The practice of bucket brigades

Benjamin Franklin played a significant role in organizing volunteer fire companies in Philadelphia starting in 1736. Firefighting became competitive, with companies vying for bonuses from insurance companies based on saving insured buildings. Annual town parades highlighted elaborate uniforms and decorated equipment.

The introduction of steam fire engines in London in 1829 and New York in 1841 faced resistance from firefighters accustomed to manual equipment. The adoption of telegraph-based fire alarm systems in Boston in 1852 improved response times. Horses were eventually integrated into firefighting, aiding in pulling heavy apparatus until motorized vehicles took over in the early 20th century.

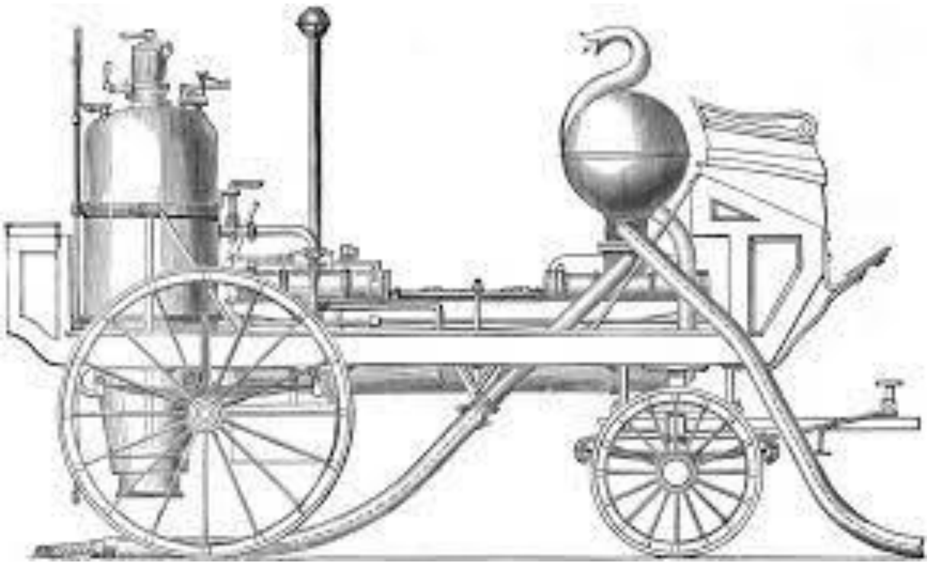

Figure 4 steam fire engines in London in 1829

Modern firefighting equipment, typically diesel-powered, has evolved to handle diverse emergencies. The legacy of early firefighting traditions, from bucket brigades to competitive fire companies, has shaped the profession into its current form, emphasizing rapid response and advanced technology.

Figure 5 Modern firefighting equipment

2 HOW DOES THE CTESIBIO PUMP WORK

Ctesibius (happy-international-inventors-day-from-samoa, s.d.) possessed an exceptionally advanced understanding of hydraulics, which enabled him to develop a system using valves that, when paired, could alternate the suction of water. This innovation allowed for increased fluid pressure through direct action, enabling it to be propelled over great distances. Such technology proved invaluable not only for firefighting but also for water evacuation in mines.

These valves operated with a unique alternation of opening and closing, driven by the fluid pressure balance. They also maintained a dynamic seal, preventing the pump from losing prime or pressure—a feature that demanded significant expertise in their construction. This sophisticated design underscored Ctesibius' mastery in hydraulic engineering.

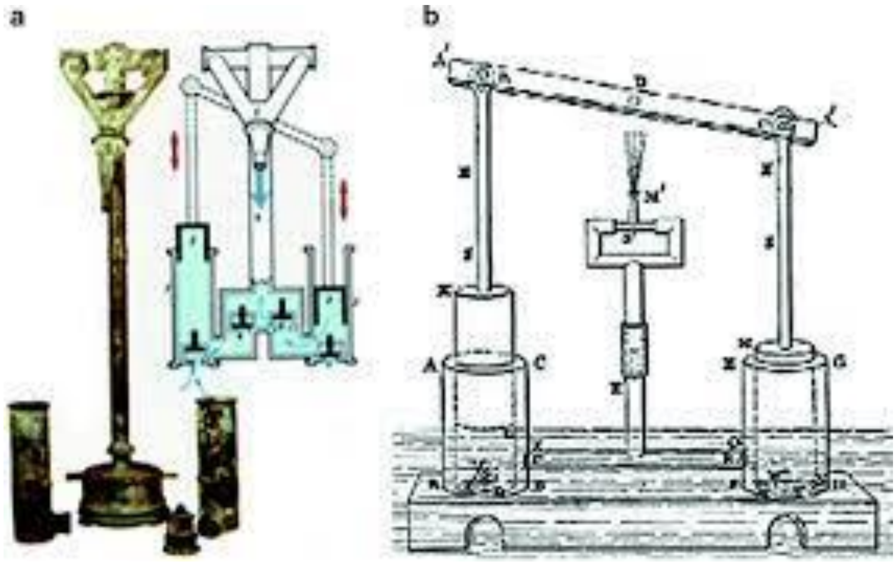

Figure 6 working mechanism of ctesibius pump

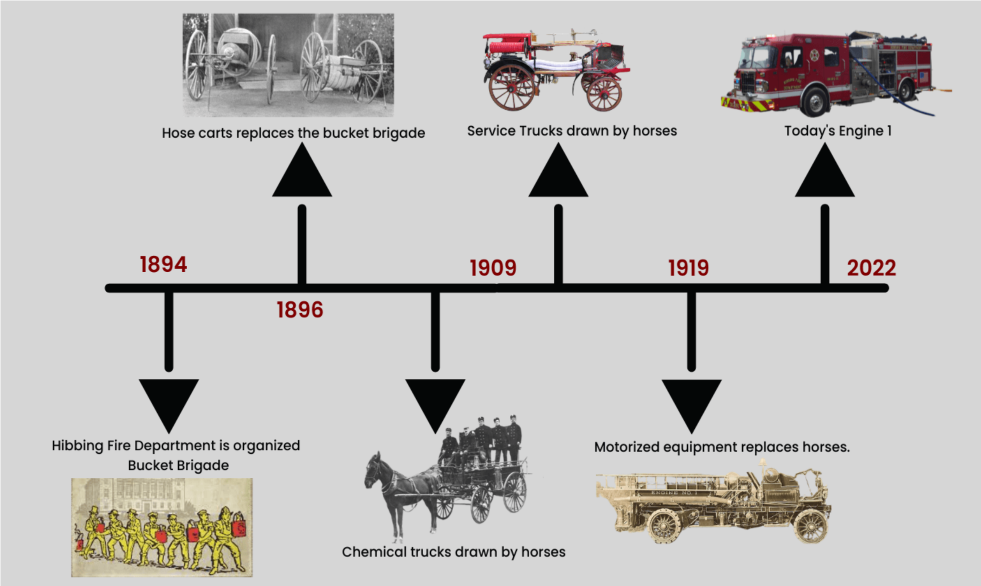

Figure 7 The firefighting time line

3 CHALLENGES FACED BY FIREFIGHTINGS : A DEEPER LOOK INTO THEIR BRAVE WORLD

Firefighting is an age-old profession that demands incredible courage, resilience, and physical prowess. Firefighters risk their lives daily to ensure the safety of people and property. However, the challenges they face go beyond the raging fires they extinguish. From emotional and psychological stress to environmental hazards, firefighters confront a myriad of difficulties. (innovations-and-challenges-in-fire-protection-system-manufacturing-in-india, s.d.)

3.1 PHYSICAL DEMANDS AND HEALTH RISKS

Firefighting is a physically demanding profession. Firefighters are required to wear heavy protective gear, which can sometimes weigh over 45 pounds, not including the additional weight of tools and equipment. They must work in extreme heat, navigate through smoke-filled environments, break down doors, and carry victims to safety, often under intense time pressure. This physical strain can lead to:

- ✓ Musculoskeletal injuries: Carrying heavy equipment, breaking through obstacles and even the repeated motion of pulling hoses can lead to sprains, strains, and other injuries.

- ✓ Cardiovascular issues: Sudden intense physical activity, combined with stress and heat, can increase the risk of heart attacks. Sudden cardiac events account for a significant number of firefighter line-of-duty deaths.

- ✓ Traumatic incidents: Firefighters often witness heart-wrenching scenes – from children trapped in fires to victims of car accidents. Repeated exposure to such traumatic incidents

  can lead to post-traumatic stress disorder (PTSD).

- ✓ Chronic stress: The constant need to be on alert, especially in busy departments, can lead to chronic stress. Over time, this can result in anxiety, depression, and even substance abuse.

4 TECHNOLOGIES THAT WILL TRANSFORM INDUSTIAL FIRE FIGHTING

Industrial fires present significant hazards to facilities, personnel, and nearby communities ,When flammable materials are released they can result in a variety of dangerous events such as fireballs and pool fires, flash fires, flares, jet fires, and even unconfined vapor cloud explosions.

Industrial facilities are at high risk for explosions, chemical releases, and rapidly spreading fires based in last statistics In U.S approximately 37,000 industrial fires occur annually, leading to an average of 18 deaths, 279 injuries, and $1 billion in direct property damage.

However advancements in technology are increasingly influencing industrial fire operations as we move into 2024, new innovative gadgets and devices are expected to aid fire brigades in preventing and extinguishing fires the following are some technological breakthroughs poised to make a lasting impact on industrial firefighting in the coming years.

4.1 FIREFIGHTING DRONES

Firefighting drones (new-technology-wildfires, s.d.) have emerged as a game-changing tool These aerial marvels equipped with advanced technology revolutionize firefighting by enhancing situational awareness improving safety and optimizing efficiency.

Figure 8 Drone Forest fire fighting

The risks of explosion toxic fumes and hazardous chemicals in industrial fires are increasing, According to Barry Alexander founder and CEO of Aquiline Drones drones can provide a more comprehensive view of fire scenes from multiple angles "Drones give you a complete picture of the scene while keeping humans out of harm's way" he explains.

Drones deliver aerial imagery that significantly enhances situational awareness With new low-cost thermal imaging solutions drones can improve visibility in challenging conditions This technology allows drones to "see" through smoke providing crucial information to firefighters Incident commanders benefit from real-time video feeds overlaid area topography and maps which offer insights that enhance firefighting efforts When drones fly overhead they can detect hidden fires in roofs and walls offering better protection for firefighters. Additionally if people are still inside the building this technology can help locate them accurately.

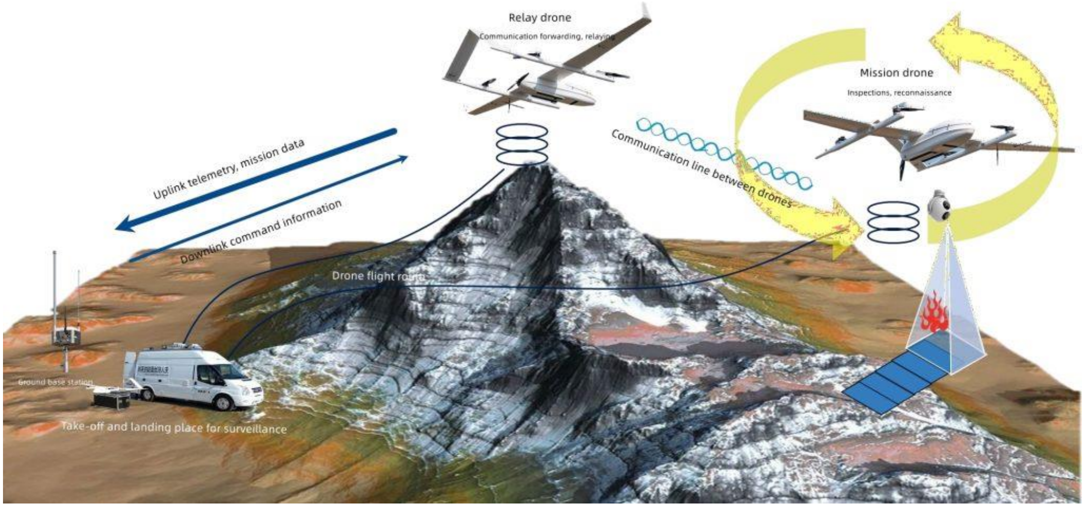

Figure 9 Emergency communication and coordination

4.2 FIREFIGHTING ROBOTS

Fires pose a huge danger to human life but robots can directly fight fires in ways that would put humans at risk, With heat-sensing cameras and onboard water or other fire retardants these machines can navigate steep terrain or enter burning homes to fight fires directly Most of the robots currently in use are controlled remotely by firefighters but researchers are beginning to combine AI with robots that enable the robots to make decisions about the best firefighting strategies on their own.

Figure 10 Firefighter Robots

Fires present a significant threat to human life but robots have the capability to combat fires in situations that would be too dangerous for humans Equipped with heat-sensing cameras and onboard systems for deploying water or other fire retardants these machines can traverse steep terrain or enter burning buildings to tackle fires directly While most robots in use today are remotely operated by firefighters researchers are now exploring the integration of AI allowing these robots to independently determine optimal firefighting strategies.

4.3 AI AND MACHINE LEARNING

The application of artificial intelligence (AI) and machine learning in disaster management has garnered increasing interest As a subset of machine learning allows computers to learn and provide insights without explicit programming for specific tasks This technology holds significant promise for firefighting teams enabling them to analyze historical and current wildfire data effectively when planning fire response strategies.

Figure 11 FireMapp AI technology

AI algorithms can forecast fire behavior such as FireMap an AI predictive mapping platform developed by WIFIRE Lab that takes in satellite and ground sensor, camera, and aerial infrared data and accounts for weather, topography, drought conditions and other factors to build out the projected trajectory of a wildfire.

5 COMPARISON WITH EXITSING FIREFIGHING TECHNOLGIES

A comprehensive analysis is conducted to compare the developed remote-controlled firefighting hose system with existing firefighting technologies, The evaluation addresses several critical aspects, including safety, efficiency, accessibility, and deployment speed.

	RoboTube	**Traditional FH**	**Advanced Drones**	**Existing FR**
Safety	Significantly reduces risks via remote operation	Direct exposure to hazards, moderate safety	Minimizes risks with remote operation	Ensures high safety with remote control
Efficiency	High operational efficiency with precise control	Moderate efficiency, manual handling required	High efficiency, rapid response	High efficiency with advanced controls
Accessibility	Excellent access to confined and elevated spaces	Limited by firefighter mobility	Good access, depending on drone capability	Moderate to good, depending on robot design
Deployment Speed	Rapid deployment, quick setup	Moderate deployment speed, manual setup needed	Rapid deployment	Variable, typically moderate
Cost	Moderate, advanced component costs	Low, basic equipment	High, costly technology	High, advanced technology and components
Maintenance	Moderate, requires maintenance of complex parts	Low, simple and durable components	High, sensitive and complex systems	High, involves complex components
Human Resources	Low, fewer personnel needed due to remote operation	High, multiple firefighters required	Low, remote operation	Low, remote operation
Operational Range	Extensive, remote control allows large range	Limited by hose length and firefighter reach	Extensive, large area coverage by drones	Variable, often good depending on mobility and hose length

Table 1 Comparative Study of firefighting innovations

- **FHS**: Firefighting House System
- **FH**: Firefighting Houses
- **FR**: Firefighting Robots

The RoboTube system presents significant advancements over existing firefighting technologies because This innovative system inspired by vine robots and pipe relining techniques offers numerous benefits in terms of safety and efficiency, accessibility, and deployment speed.

Safety One of the primary advantages of the developed system its ability to be controlled remotely significantly reducing the risk to human firefighters, The system unique design composed of two main parts, ensures that the expensive and critical components remain safely behind the firefighting truck away from immediate danger and This reduces the potential consequences of damage compared to other technologies.

Efficiency and Accessibility The system's ability to navigate towards the target without friction due to its unique deployment mechanism enhances its efficiency in reaching fire sources This feature allows for better access to confined spaces and elevated areas that traditional methods and some advanced robots and drones struggle to reach, The firefighting hose system can also create a protective water shield that safeguarding both the robot and firefighters from the fire while simultaneously fighting the fire with high-pressure water stream using the innovative nozzel that change the direction of the fire hose using the joystick.

Deployment Speed The rapid deployment capability of the system is another notable improvement Unlike conventional firefighting equipment that may require significant setup time this system can be quickly deployed providing immediate assistance in critical situations, This rapid response can be crucial in minimizing damage and saving lives.

6 ROBOT TUBE OVERVIEW

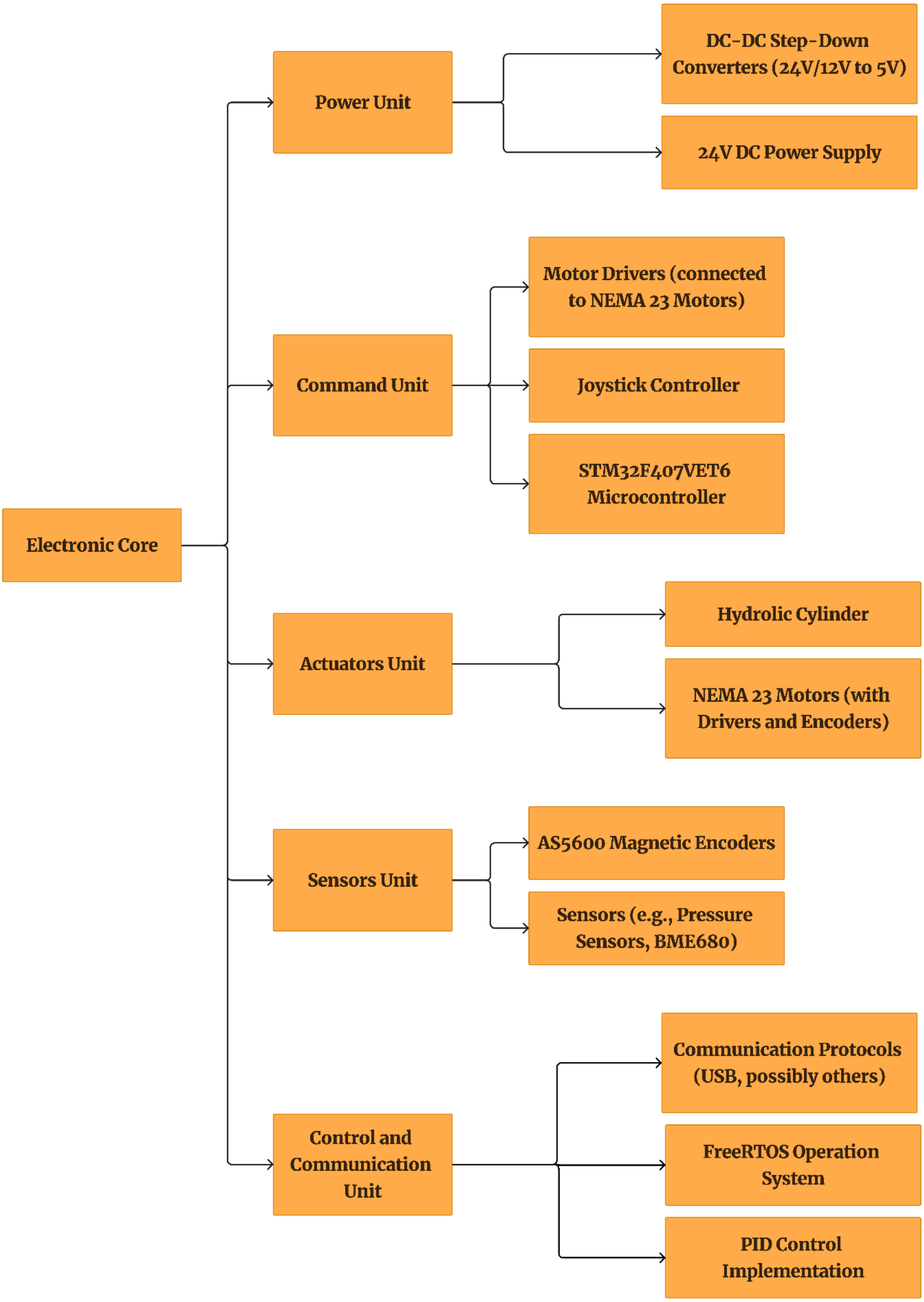

Figure 12 Electronic Core part

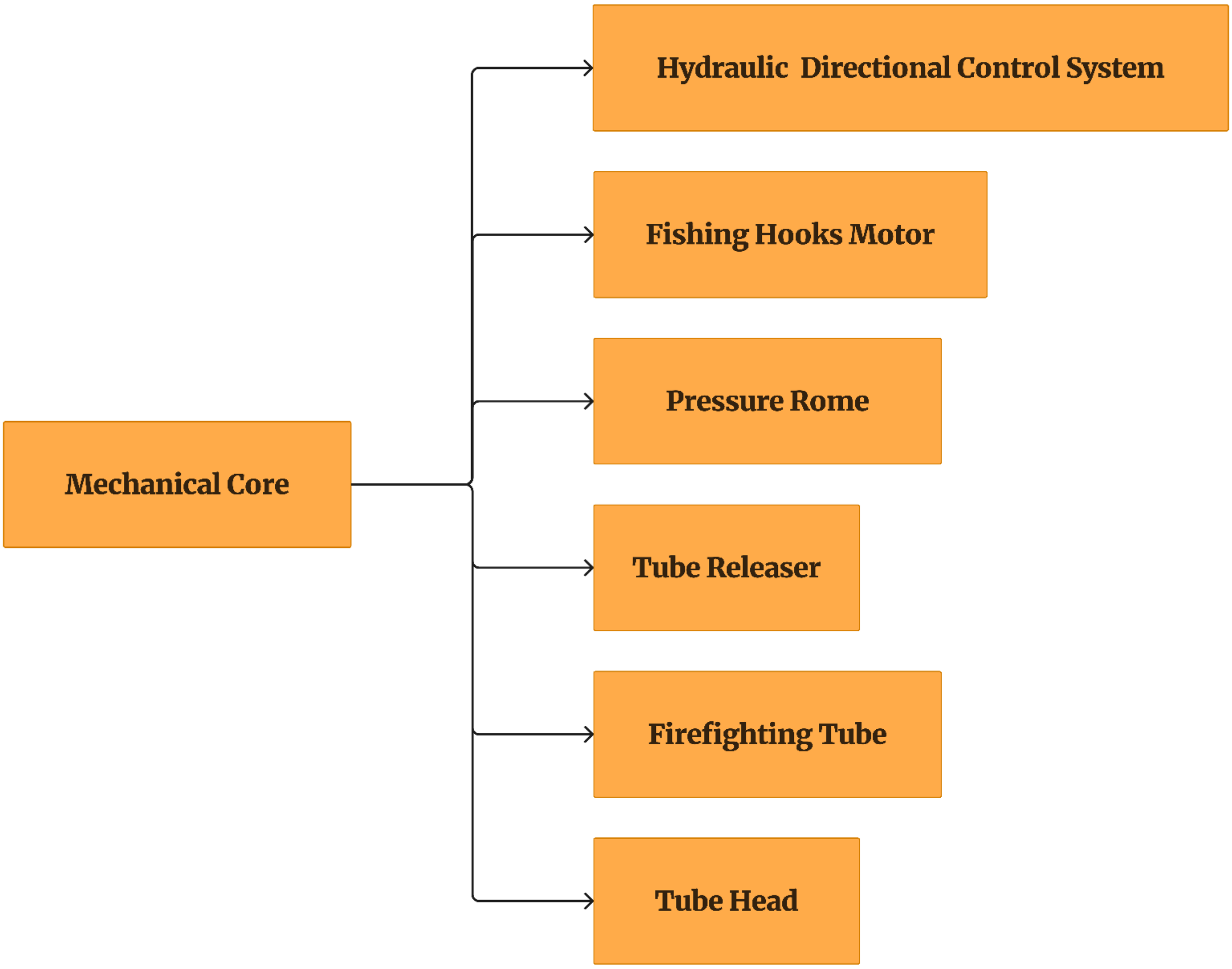

Figure 13 Mechanical Core Part

7 CONCLUSION

Firefighting has evolved from basic tools and methods to advanced, technology-driven solutions. Despite these advancements, challenges include hazardous and complex environments and the need for rapid and effective response. The introduction of remote-controlled firefighting hose systems, as developed in this project, addresses these issues by enhancing safety, accessibility, and efficiency. This system, which uses cutting-edge components like microcontrollers and motors, offers superior performance compared to traditional hoses and some advanced firefighting robots. These innovative technological advancements promise significant improvements in firefighting operations, setting the stage for detailed exploration in subsequent chapters.

Chapter ll

MECHANICAL DESIGGN

1 INTRODUCTION

This chapter delves into the mechanical design aspects of the remote-controlled firefighting hose system, emphasizing the crucial role that the **SOLIDWORKS** application plays in the design process, the objective is to provide a comprehensive understanding of how the mechanical components were conceptualized, designed, analyzed, and optimized to create an effective and reliable firefighting solution. By examining these aspects, this chapter highlights the importance of mechanical design in ensuring the overall performance and reliability of the firefighting system.

2 SOLIDWORKS SOFTWARE

SOLIDWORKS is used by millions of designers and engineers at hundreds of thousands of companies. It's one of the most popular design and engineering software on the market. Known for its range of features and high functionality, SOLIDWORKS is used across multiple professions and industries around the world.

SOLIDWORKS uses parametric design, which is why it's such an effective tool for designers and engineers, this means that the designer can see how changes will affect its neighboring components, or even the overall solution. For example, if the size of a single component is increased, this would affect the joint or whole it's attached to. This allows designers to spot and correct issues quickly and easily.

Figure 14 SolidWorks logo program

3 SOLIDWORKS FEATURES

- Simple but sophisticated 3D CAD design
- Use templates and the CAD library for improved efficiency
- Automation and design reuse to speed up the process
- Cost estimation tools allow you to keep track in real-time
- Ensure potential risks are caught early with interference check
- Quickly produce 2D drawings for production
- Easily create animations and photorealistic renderings

4 CAPABILITIES OF SOLIDWORKS

As mentioned above, SOLIDWORKS is a parametric CAD program which is easy to use and highly efficient that makes it a favorite for both students and experienced designers.

As with most software familiarizing yourself with the buttons, names, and User Interface can take some time however, there are some great, unique functions to aid new users in this process and optimize for the best user experience and, there are many helpful tutorials available that offer great insight and an introduction to the design process.

4.1 RENDERING

SOLIDWORKS Visualize allows designers to create presentation-ready, photorealistic renderings CAD files can be opened directly in SOLIDWORKS and rendered using accurate textures, reflections, and lighting. This is a powerful feature used by most designers but is particularly useful for product designers as it allows them to demonstrate their final concept before going into production.

4.2 SOLIDWORKS SIMULATION

SOLIDWORKS Simulation allows designers to put their designs to the test, and quickly and accurately identify any flaws. The designer will be provided with highly accurate data, which means they can make changes to the design before a physical prototype is produced. Mechanical engineers can save a lot of time, money, and effort by identifying issues with their designs early in the process.

4.3 INTRICATE EVALUATION

The Drawings tool allows a designer to quickly create 2D representations of any aspect of a design, with the option to add dimensions with the click of a button. This is useful for designers, engineers, and architects, offering the ability for a thorough evaluation.

4.4 MANUFACTURE WITH EASE

Once the design is complete, and the designer has eliminated potential risks identified in the simulation and evaluation, a prototype can be made. SOLIDWORKS CAM produces the design files that can be sent straight to production. The software also includes a searchable database of 3D Printers generating 2D slice data from solid geometry, while the 3DEXPERIENCE Marketplace enables you to outsource prototype and part manufacturing from right inside the UI (User Interface).

5 THE MAIN ADVANTAGE OF SOLIDWORKS

While there are some potential disadvantages, the advantages of SOLIDWORKS by far outweigh any issues that a user may encounter.
Below are just some of the main advantages of using SOLIDWORKS:

5.1 EASY TO LEARN

The biggest stumbling block new SOLIDWORKS users have is learning a brand new interface. However, there are SOLIDWORKS tutorials available to guide you through the interface, meaning those experienced with CAD and CAE should have no problems getting to grips with it.
SOLIDWORKS helps new users by not throwing too much at them all at once, and has plenty of educational aids to allow learners to go at their own pace.
TECHNIA offers a range of SOLIDWORKS support training, for both experienced and new designers.

5.2 EASY PACKAGE DESIGNS IN 2D AND 3D FORMS

SOLIDWORKS makes it quick and simple to share designs in 2D or 3D formats, meaning you can get instant feedback and continue to work on your designs.
Designs can even be shared as 3D animations, which allows you to accurately demonstrate new products and features.

5.3 AUTOMATION MADE EASY

Save time, money and energy by allowing SOLIDWORKS to automate part of the process. SOLIDWORKS can automate dimensioning of 3D CAD models, set certain rules and parameters to speed up duplication for creating design variations.

6 MECANICAL DESIGN AND SIMULATION

6.1 TUBE RELEASER

6.1.1 MECHANISM

Controls the smooth and steady release of the firefighting tube, preventing kinks and ensuring reliable deployment towards the fire.

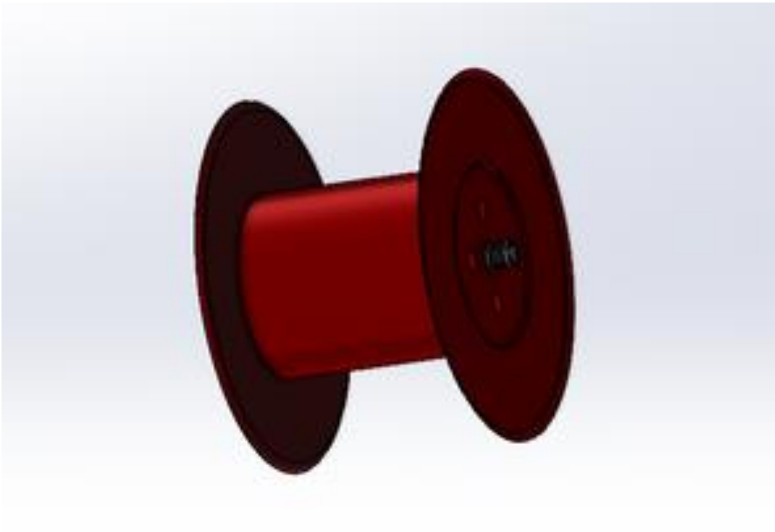

Figure 15 Tube Releaser 3D Model

6.2 STEPPER NEMA MOTOR 23

6.2.1 MECHANISM

6.2.1.1 STEPPER MOTOR BASICS

- **Stepper motors** are brushless, synchronous electric motors that convert digital pulses into mechanical shaft rotation.

They move in discrete steps, allowing precise control of position and speed.

6.2.1.2 CONSTRUCTION

- **Stator**: The stationary part of the motor, consisting of coils arranged in phases when energized, these coils generate a magnetic field.
- **Rotor**: The rotating part of the motor, typically a permanent magnet or a soft iron core with teeth that align with the magnetic field.

6.2.1.3 WORKING PRINCIPLE

- **Magnetic Fields and Poles**: When current flows through the stator coils, it creates magnetic poles that attract or repel the poles on the rotor.
- **Stepping**: The motor rotates in fixed steps, usually defined by the motor's design (e.g., 1.8 degrees per step for 200 steps per revolution).

6.2.1.4 PHASES AND STEP SEQUENCE

- **Bipolar Motors**: Have two coils, requiring a more complex driver circuit but providing more torque. Each coil must be energized in both directions.
- **Unipolar Motors**: Have four coils, each coil can be energized in one direction, simplifying the driver circuit but usually producing less torque.

6.2.1.5 DRIVING METHODS

- **Full Step Drive**: Energizes one or two phases at a time, moving the motor one step at a time.
- **Half Step Drive**: Alternates between energizing one and two phases, effectively doubling the number of steps per revolution and providing smoother motion.
- **Microstepping**: Involves controlling the current through the coils to create intermediate steps, allowing for finer resolution and smoother motion.

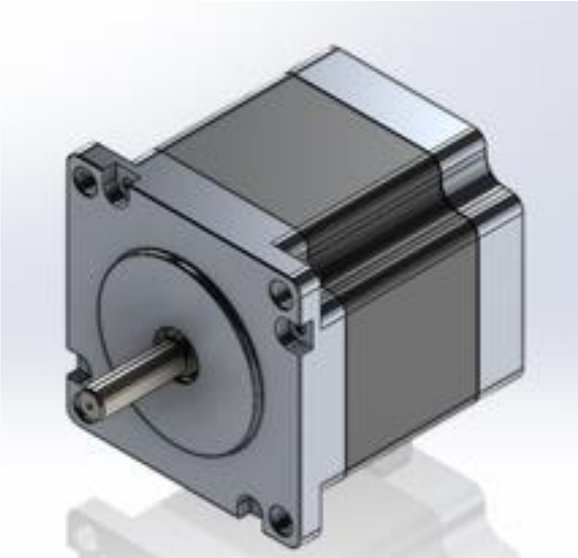

Figure 16 Stepper Motor 3D Model

6.3 GEAR ASSEMBLY 3D MODEL

6.3.1 COMPONENETS OF THE DUAL-TEETH GEAR ASSEMBLY

- **Pinion Gear**: This smaller gear meshes with the teeth on the inner circumference of the ring gear.
- **External Gear**: Another gear that meshes with the teeth on the outer circumference of the ring gear.

6.3.2 TERMINOLOGY AND CALCULATIONS

6.3.2.1 NUMBER OF TEETH (N)

$$\mathbf{N} = \frac{\boldsymbol{PCD}}{\boldsymbol{m}}$$

6.3.2.2 MODULE (m)

Ratio of pitch diameter to the number of teeth.

$$\mathbf{m} = \frac{\mathbf{PCD}}{\mathbf{N}}$$

6.3.2.3 CIRCULER PITCH (p)

Distance from one point on a tooth to the corresponding point on the next tooth along the pitch circle.

$$\mathbf{P} = \frac{\boldsymbol{\pi}\mathbf{PCD}}{\mathbf{N}}$$

6.3.2.4 ADDENDUM (a)

Radial distance between the pitch circle and the addendum circle (the outermost circle).

$$\mathbf{a} = \mathbf{m}$$

6.3.2.5 PITCH DIAMITER (PCD)

Diameter of the pitch circle.

$$\mathbf{PCD} = \mathbf{m} \cdot \mathbf{N}$$

6.3.2.6 ADDENDUM CIRCLE (Da)

Circle that bounds the outermost points of the teeth.

$$\mathbf{Addendum\ Circle} = \mathbf{PCD} + \mathbf{2} \cdot \mathbf{m}$$

6.3.2.7 DEDENDUM (d)

Radial distance from the pitch circle to the dedendum circle (the root circle).

$$\mathbf{d} = \mathbf{1.25} \cdot \mathbf{m}$$

6.3.2.8 DEDENDUM CIRCLE (Dr)

Circle that bounds the innermost points of the teeth.

$$\mathbf{Dr = PCD \cdot 2 \cdot d}$$

6.3.2.9 BASE CIRCLE (Db)

Circle from which the involute profile of the gear tooth is generated.

$$\mathbf{Db = PCD \cdot \csc \vartheta}$$

6.3.2.10 CLEARANCE (C)

Radial distance between the top of a tooth on one gear and the bottom of the mating tooth space on the other gear.

$$\mathbf{C = 0.25 \cdot m}$$

6.3.2.11 CLEARANCE CIRCLE (Dc)

Circle that bounds the top of the spaces between the teeth on a gear.

$$\mathbf{Dc = m \cdot (N - 2)}$$

6.3.2.12 WHOLE DEPTH (h_t)

Total depth of the tooth space, equal to the sum of the addendum and the dedendum.

$$\mathbf{ht = m \cdot 2.25}$$

6.3.2.13 CENTER DESTENCE (C)

Distance between the centers of two meshing gears.

$$\mathbf{C = \frac{PCD1 + PCD2}{2}}$$

6.3.2.14 GEAR RATIO (GR)

Ratio of the number of teeth on the driven gear to the number of teeth on the driving gear.

$$\mathbf{GR = \frac{Ndriven}{Ndriving}}$$

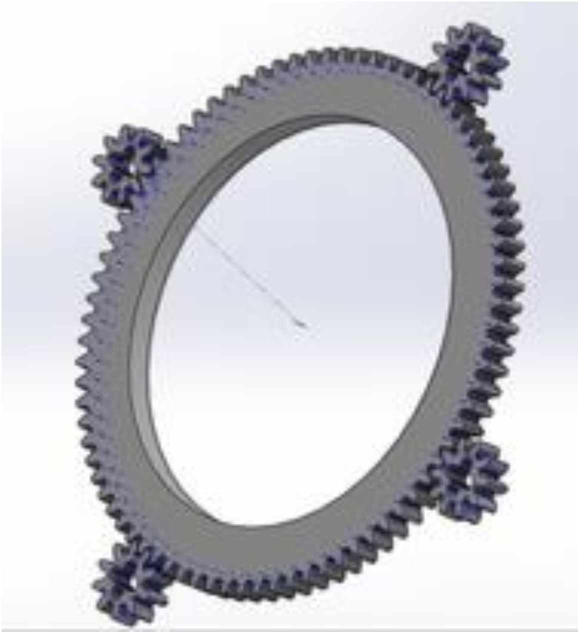

Figure 17 Gear Assembly 3D Model

6.4 COOLIING UNIT 3D MODEL

Figure 18 Cooling Unit 3D Model

7 CONCLUSION

The mechanical design of the firefighting robot is a testament to innovative engineering aimed at enhancing the safety and efficiency of firefighting operations, The mechanical framework, built around robust and precise components, ensures that the robot can withstand the harsh conditions encountered during fire suppression tasks.

The use of SolidWorks for detailed design and modeling has allowed for meticulous planning and optimization of each component, ensuring that the mechanical structure can handle the stresses and strains of operation.

ChapterIII

ELCTRONIC SYSTEMS AND CONTROL

1 INTRODUCTION

In this chapter, we delve into the electronic components and systems that form the backbone of the remote-controlled firefighting robot the electronic part is crucial for controlling the mechanical movements, processing sensor data, and ensuring seamless communication between various modules, this chapter covers the selection, functionality and integration of key electronic components, including the **STM32F407VET6** microcontroller, **NEMA 23** motors with their respective drivers and encoders, power supplies, **DC-DC** step-down converters and various sensors, additionally we discuss the implementation of **FreeRTOS** for task management and the application of PID control for precise motor operation. By understanding these electronic components and their roles, we can appreciate how they collectively contribute to the robot's ability to effectively and safely combat fires.

2 STM32F407VET6 DESCRIPTION AND USAGE

2.1 DESCRIPTION

The STM32F405xx and STM32F407xx family is based on the high-performance Arm Cortex-M4 32-bit RISC core operating at a frequency of up to 168 MHz The Cortex-M4 core features a Floating point unit (FPU) single precision, which supports all Arm single-precision data-processing instructions and data types it also implements a full set of DSP instructions and a memory protection unit (MPU) which enhances application security.

(STM32CubeIDE:Introduction_to_STM32CubeIDE, s.d.)

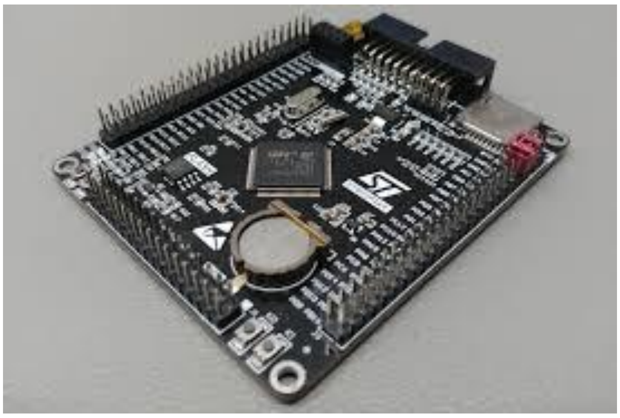

Figure 19 STM32F407VET6 board

STM32F407xx family incorporates high-speed embedded memories (Flash memory up to 1 Mbyte, up to 192 Kbytes of SRAM), up to 4 Kbytes of backup SRAM and an extensive range of enhanced I/Os and peripherals connected to two APB buses three AHB buses and a 32-bit multi-AHB bus matrix.

All devices offer three 12-bit ADCs, two DACs, a low-power RTC, twelve general-purpose 16-bit timers including two PWM timers for motor control, two general-purpose 32-bit timers a true random number generator (RNG) they also feature standard and advanced communication interfaces.

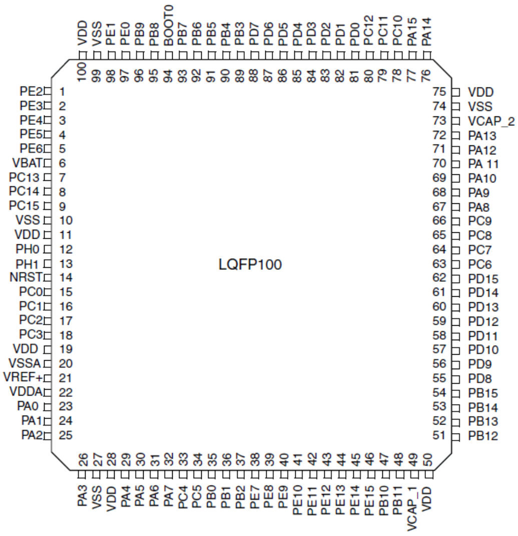

Figure 20 STM32F407VET6

2.2 SPECIFICATIONS

Supply Voltage Min Volt	Volt1.8
Supply Voltage Max	Volt3.6
Operating Temp Min Celsius	Celsius-40.0
Operating Temp Max Celsius	Celsius85.0
Core	ARM CORTEX-M4
ECCN US	3A991.A.2
ECCN EU	NEC
Packing Type	TRAY
RoHs compliant	ECOPACK2
Grade	INDUSTRIAL
Package Name	LQFP 100 14X14X1.4 MM

Table 2 STM32F407VET6 Parameters

2.3 STM32CubeIDE SOFTWARE

STM32CubeIDE is an advanced C/C++ development platform with peripheral configuration, code generation, code compilation and debug features for STM32 microcontrollers and microprocessors it is based on the Eclipse®/CDT® framework and GCC toolchain for the development and GDB for the debugging. It allows the integration of the hundreds of existing plugins that complete the features of the Eclipse® IDE.

(stm32cubeide, s.d.)

Figure 21 STM32CUBEIDE Program

STM32CubeIDE integrates STM32 configuration and project creation functionalities from STM32CubeMX to offer all-in-one tool experience and save installation and development time after the selection of an empty STM32 MCU or MPU or preconfigured microcontroller or microprocessor from the selection of a board or the selection of an example the project is created and initialization code generated at any time during the development, the user can return to the initialization and configuration of the peripherals or middleware and regenerate the initialization code with no impact on the user code.

STM32CubeIDE includes build and stack analyzers that provide the user with useful information about project status and memory requirements.

STM32CubeIDE also includes standard and advanced debugging features including views of CPU core registers, memories, and peripheral registers as well as live variable watch, Serial Wire Viewer interface or fault analyzer.

2.3.1 USAGEE IN THE PROJECT

The STM32F407VET6 serves as the main controller for the firefighting robot, handling motor control, sensor data processing, and communication with the remote control interface it is programmed using STM32CubeIDE.

2.3.2 STM32CubeIDE OVERVIEW

Figure 22 Launch STM32CubeIDE

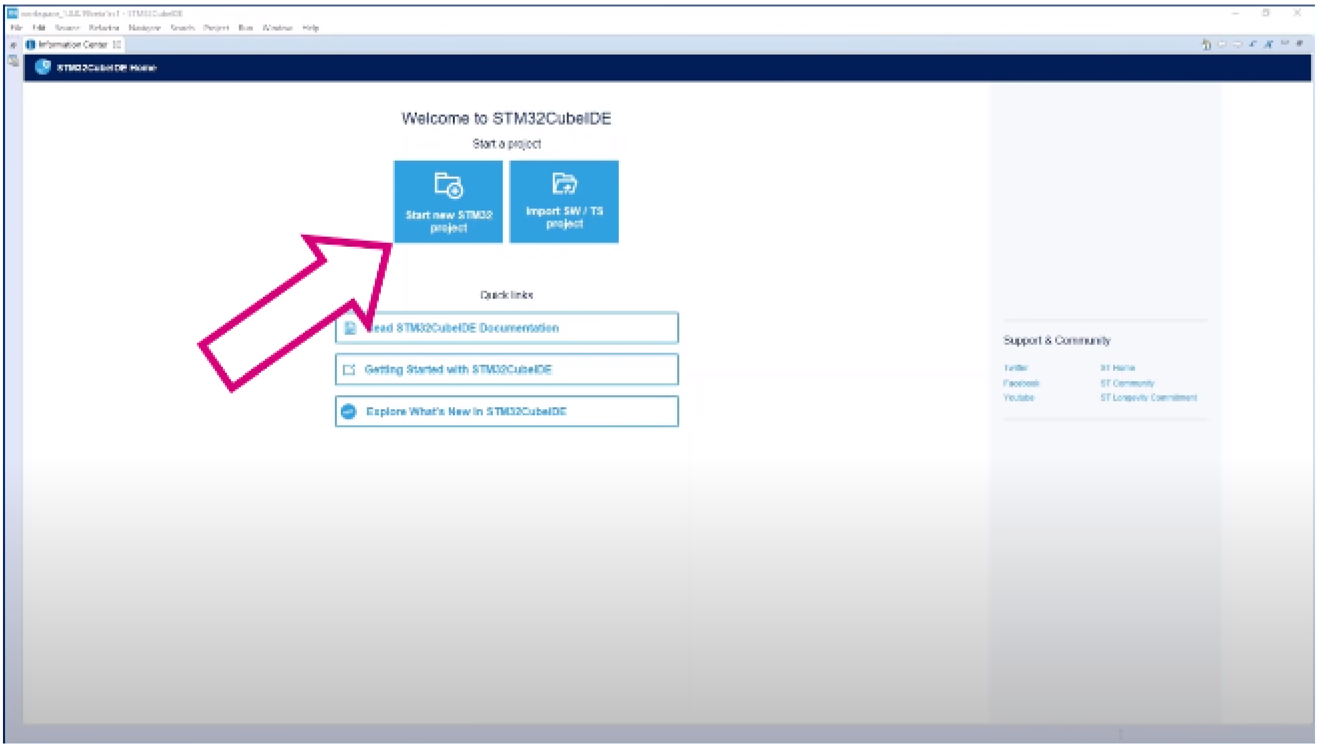

Figure 23 Start new STM32 Project

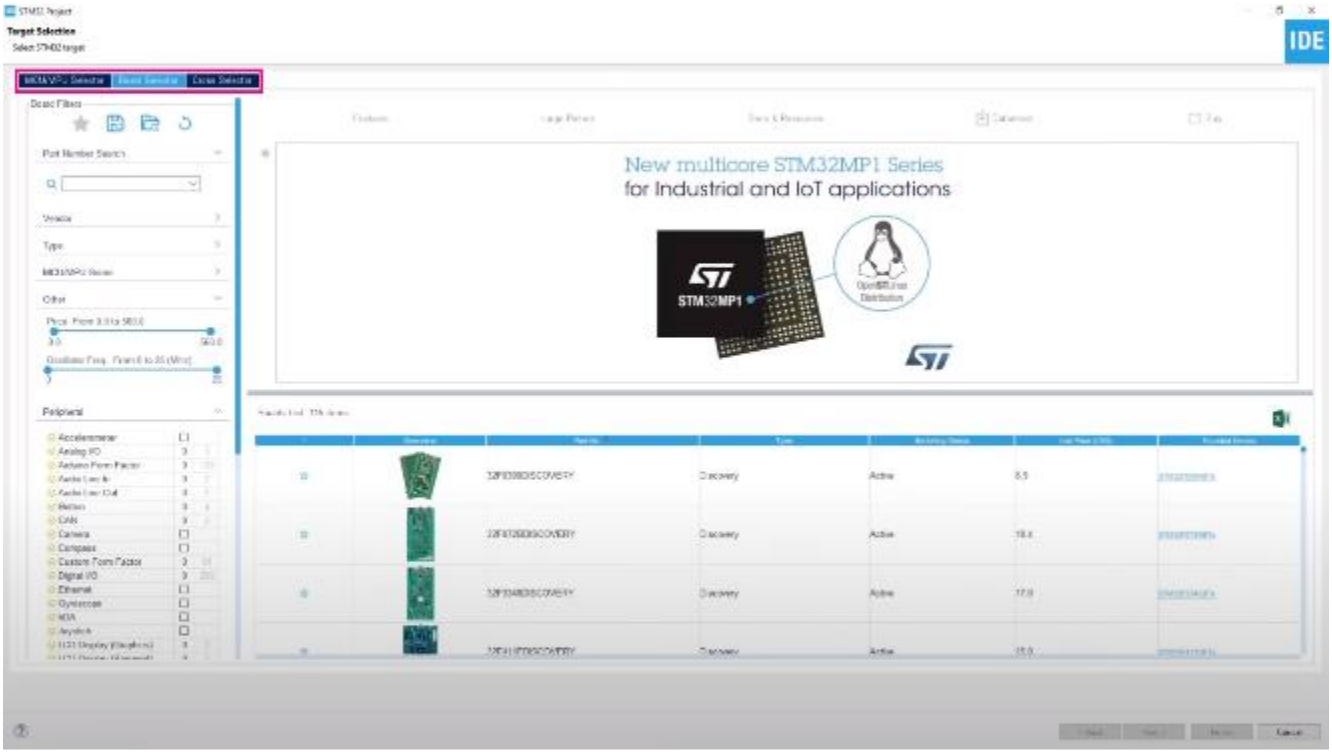

Figure 24 Select an MCU or a Board

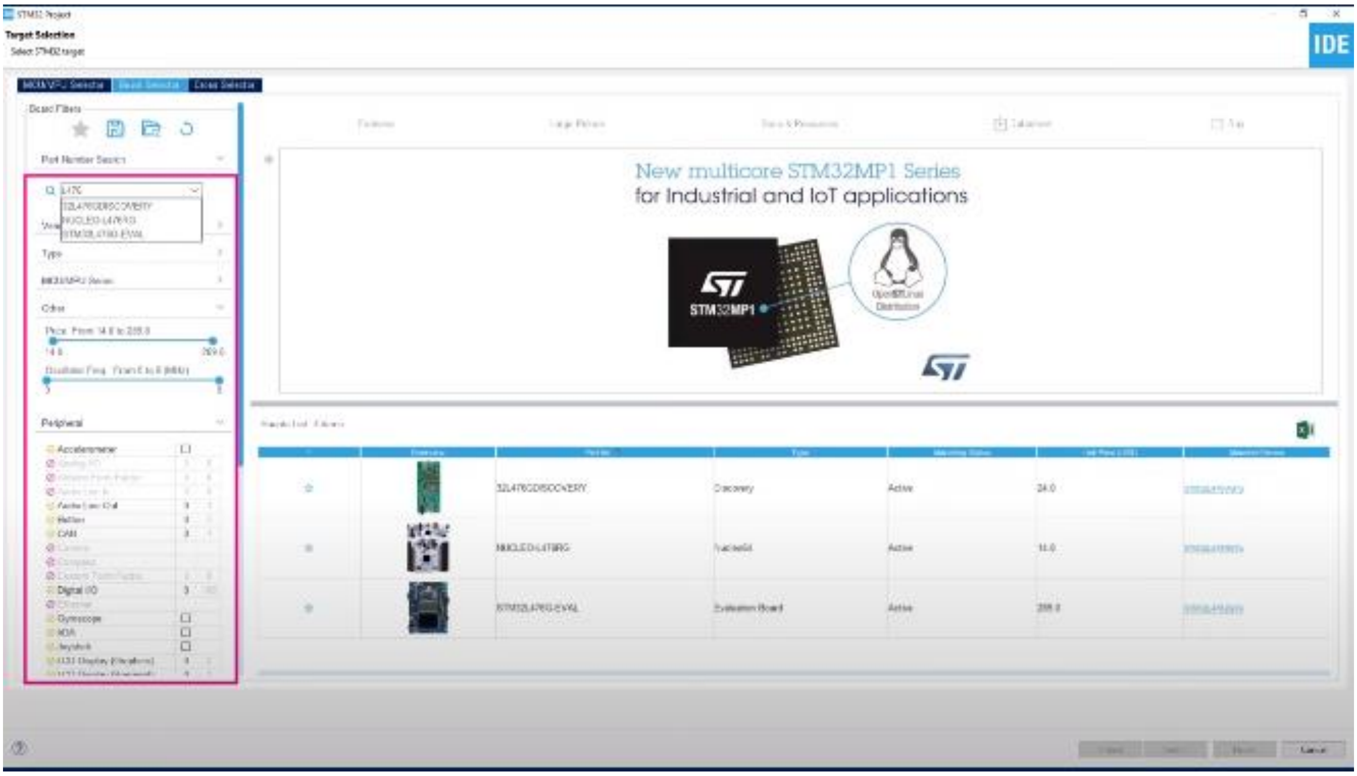

Figure 25 Use the helpful filters to make a choice

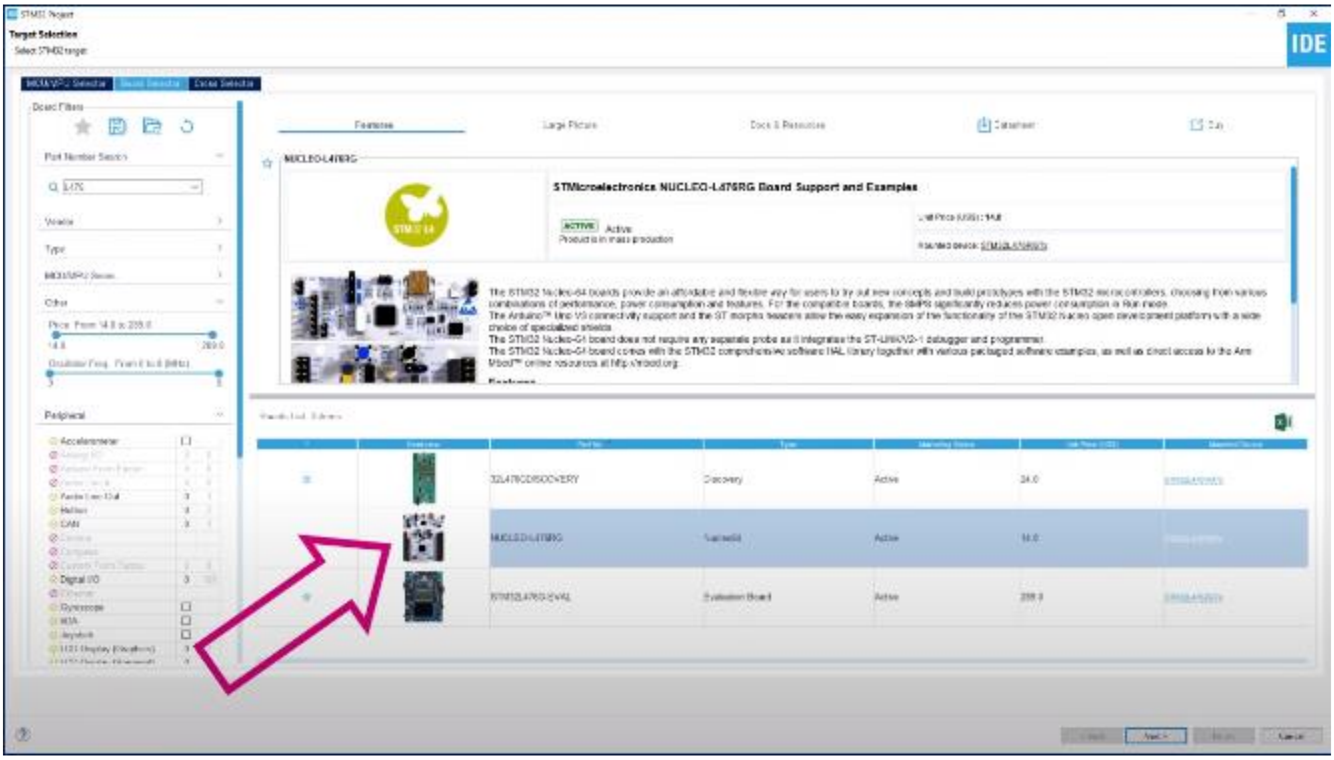

Figure 26 Select the Board

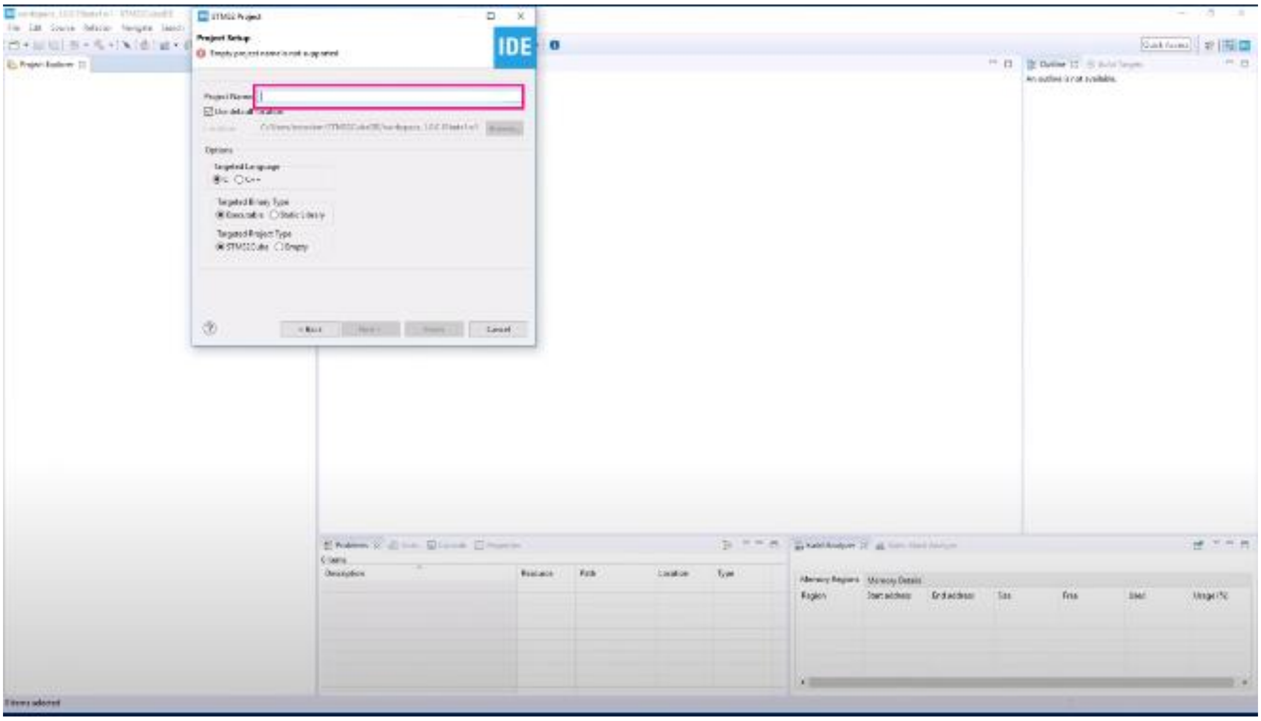

Figure 27 Enter a Project Name and select the necessary options

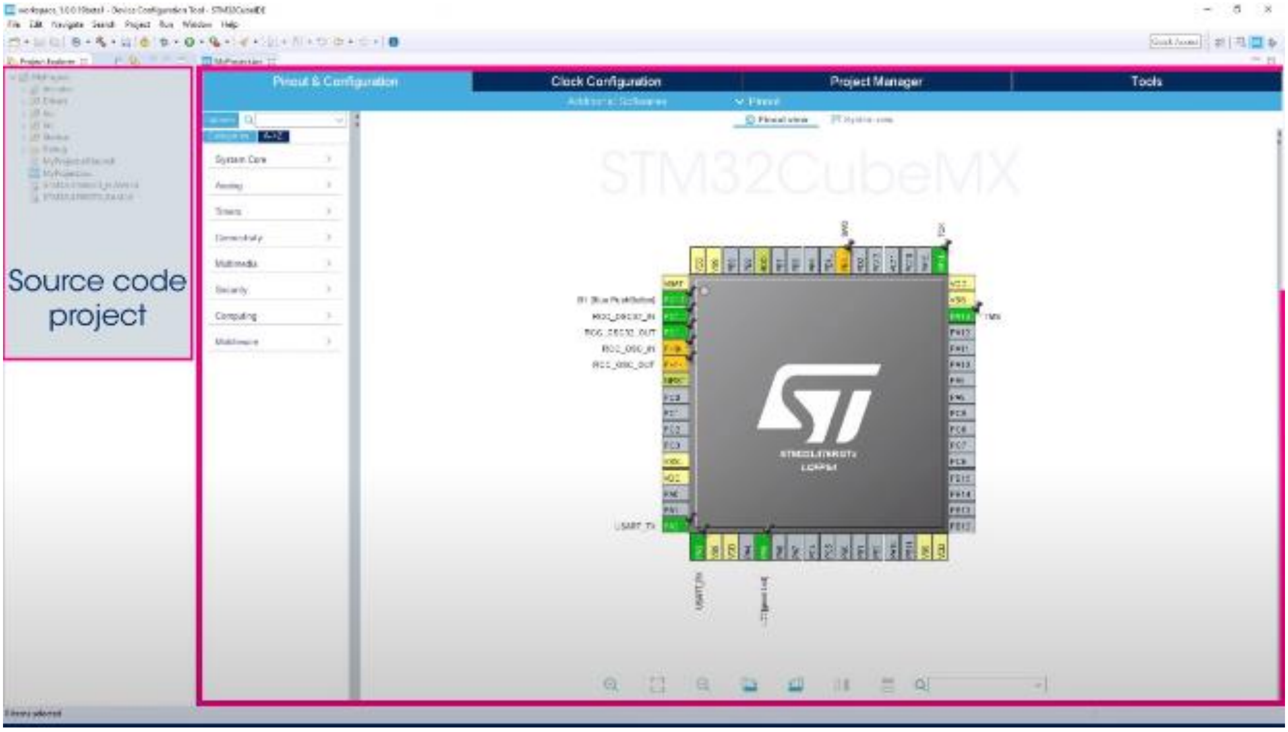

Figure 28 The Project is now created

3 NEMA STANDARDS

3.1 DEFINITION

NEMA standards are the North American equivalent of IEC electric motor standards, and they primarily focus on the type of enclosure electrical components have (though NEMA standards encompass far more than this) manufacturers can choose to design and produce components that comply with NEMA standards but this is a voluntary distinction for electrical component manufacturers. (motor-generator, s.d.)

Electrical enclosures with a NEMA rating meet certain standards related to protection from corrosion, dust, and chemical damage, these standards updated every five years and communicate to potential purchasers the level of durability that electrical enclosures have in certain environmental conditions, non-NEMA motors and electrical enclosures can be just as safe as or even safer than NEMA products based on the regulations and quality standards of the specific manufacturer. (what-are-nema-motor-standards, s.d.)

3.2 NEMA DESIGN CLASSES

NEMA standards establish four distinct design classes. Motors that fall within each design class have different characteristics are manufactured to have different levels of durability in their operational environments. The four NEMA design classes are:

3.2.1 NEMA Class A

Electric motors within NEMA Classes A, B, and C each have a maximum 5% slip standard. NEMA Class A motors must meet that standard with a medium or high starting current. They must also have a normal breakdown torque or the maximum torque at a rated voltage and frequency level without decreasing in speed, and locked rotor torque, the torque the motor develops from a zero-speed start. NEMA Class A motors are trusted in a wide variety of commercial, industrial, and building applications, such as in fans and pump systems.

3.2.2 NEMA Class B

NEMA Class B motors must also have a normal breakdown torque just like Class A motors, however, they need to have a low starting current and be able to accommodate normal starting torque levels they also must be able to provide or withstand a high locked rotor torque, this distinction is ideal for motors that will power elements through HVAC systems.

3.2.3 NEMA Class C

NEMA Class C motors share many of the requirements of NEMA Class B products. However, they're built for applications with a high starting torque and high level of inertia, such as large conveyor systems and heavy-duty systems.

3.2.4 NEMA Class D

NEMA Class D motors are built for high-inertia applications, such as oversized equipment including cranes and hoists found in construction or mining settings. These motors have a low starting current but a high locked rotor torque they also have a maximum slip range of 5 to 13%.

3.3 NEMA MOTORS AND GENERATORS

The electric motor converts electrical energy into mechanical energy motors convert approximately 50% of all electricity into motion for driving modern society products consist of motors rated from 1/1,000 up to 50,000 HP and rated up to 13,800 volts, they include fractional horsepower (HP) motors, medium AC and DC machines and large AC and DC machines.

The NEMA Premium energy efficiency motors program the first verification program of its kind for motor efficiency, is often specified in commercial, industrial, and government contracts to help purchasers optimize motor systems efficiency, reduce electrical power consumption and costs and improve system reliability.

As the voice of the industry Members collaborate with regulators other trade associations and other electro industry stakeholders to develop Standards and policy.

3.4 NEMA 23 MOTOR

The NEMA 23 motor is a type of stepper motor defined by the National Electrical Manufacturers Association (NEMA) standards it is known for its precise control and reliability, making it ideal for various industrial and robotics applications. The "23" in NEMA 23 refers to the motor's faceplate size, which measures 2.3 x 2.3 inches (58.4 x 58.4 mm), this standard size ensures compatibility and interchangeability across different manufacturers and applications.

Figure 29 NEMA 23 MOTOR

3.5 SPECIFICATONS

Model	23HS5628
Phase	2
Step Angle	1.8°
Motor Frame Size	57 x 56mm
Shaft	"D" shaft 22xΦ6.35 mm
Outlet Way	"4" plug line
Motor Leads	30cm Wire
Adapter drive	Two-phase step drive
Rate Voltage	2.5V
Rated Current	2.8A
Resistance/Phase	0.9Ω
Resistance/Phase	2.5mH
Holding Torque	126 N.cm

Table 3 NEMA 23 MOTOR Specificatoins

3.6 USAGE IN THE PROJECT

Six NEMA 23 motors are used to control the movement of the firefighting tube compatible drivers drive these motors and their position is monitored using encoders to ensure precise control.

4 MOTOR DRIVER AND ENCODER

4.1 TB6600 0.2-5A NEMA STEPPER MOTOR CONTROLLER

4.1.1 DESCRIPTIOIN

A professional, easy-to-use stepper motor controller can control a two-phase hybrid stepper motor, it is compatible with Arduino and other microcontrollers that can output a 5V digital pulse signal, the B6600 stepper motor driver has a wide power input range and can operate with a 12~48VDC power supply it is capable of outputting a peak current of 5A, which is sufficient for most stepper motors. The stepper driver supports speed and direction control.

Figure 30 TB6600 0.25A NEMA 23 Motor Driver

4.1.2 SPECIFICATIONS

Power Input (VDC)	12 ~ 48
Current (A)	1 to 5
Maximum Output Current (A)	0.2 to 5
Maximum Output Power (W)	160
Operating Temperature (°C)	-10 to 45
Dimensions (mm)	(105 x 75 x 35) (Length x Width x Height)
Weight (g)	220
Shipping Weight (kg)	0.25
Shipping Dimensions (cm)	12 x 9 x 4

Table 4 TB6600 0.25A NEMA 23 Motor Driver

4.2 AS5600 MAGNETIC ENCODER

4.2.1 DESCRIPTION

The **AS5600 Magnetic Encoder** is a high-resolution contactless rotary position sensor that utilizes magnetic field sensing to determine the angle of a rotating magnet it is designed for applications requiring precise angular measurement and position feedback.

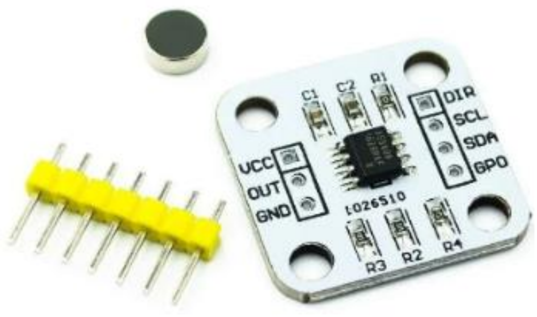

Figure 31 AS5600 Mgnetic Encoder

4.2.2 SPECIFICATIONS

Resolution	**12-bit (4096 positions per revolution)**
Interface	**I2C or PWM**
Supply Voltage	**3.3V to 5V**
power consumption	**Low**
accuracy and reliability	**High**

Table 5 AS5600 Magnitic Encoder Specifications

4.2.3 USAGE IN THE PROJECT

The AS5600 encoders are used to monitor the position of the NEMA 23 motors, providing feedback for precise control.

5 POWER SUPPLY 24V 20A

5.1 DESCRIPTION

This power supply provides the necessary power for the NEMA 23 motors and other components in the system.

Figure 32 Power Supply 24v 20A

5.2 SPECIFICATIONS

Output Voltage	24V DC
Output Current	Up to 20A
Input Voltag	110V/220V AC
Protection	Over-voltage, over-current, and short-circuit protection

Table 6 Power Supply 24V 20A

5.3 USAGE IN THE PROJECT

The power supply ensures stable power delivery to the motors, microcontroller, and other peripherals it is crucial to maintain the power supply within specified limits to prevent damage to the components.

6 DC-DC STEP-DOWN POWER CONVERTERS

6.1 DESCRIPTION

XY-3606 24V/12V to 5V 5A Adjustable Step-Down Module converts from 6-24V DC Input Voltage to 5V 5A output it automatically adjusts the output as a stable 5Volt DC output. This module can also be useful when you are powering your Raspberry Pi-based robot with a 12V Battery as it provides great efficiency it will also save battery as well, this converter is known as 24V / 12V to 5V 5A power module DC-DC XY-3606 power converter Super LM2596S....

Figure 33 DC-DC Step-Down Power Converter

6.2 SPECIFICATIONS

Input Supply voltage	9V ~ 36VDC
Output voltage	5.2V/5A/25W
Output capacity	• 9~24V input: output 5.2V/6A/30W • 24~32V input: output 5.2V/5A/25W • 32~36V input: output 5.2V/3.5A/18W
Length (mm)	63
Width (mm)	27
Height (mm)	10
Weight (gm)	22

Figure 34 DC-DC Step-Down Power Converter Specifications

6.3 USAGE IN THE PORJECT

Two XY-3606 converters are used to provide 5V power to the STM32F407VET6 the controller interface and other 5V components.

7 BME680 SENSOR

7.1 DESCRIPTION

The BME680 is the first gas sensor that integrates high-linearity and high-accuracy gas, pressure, humidity and temperature sensors It is especially developed for mobile applications and wearables where size and low power consumption are critical requirements, the BME680 guarantees - depending on the specific operating mode - optimized consumption long-term stability and high EMC robustness in order to measure air quality for personal wellbeing the gas sensor within the BME680 can detect a broad range of gases such as volatile organic compounds (VOC).

Figure 35BME680 Sensor

7.2 POSSIBLE USE CASES

- Personal air quality tracker
- Air quality mapping
- Air quality inside cars & public transport
- Enhanced context awareness
- Accurate step & calorie tracker
- Quick GPS-fix & improved navigation
- Indicator of too high / low humidity
- Air quality & well-being indicator
- Sleep / recovery tracker
- Weather trend
- Stair counter
- Floor level detection

7.3 SPECIFICATOINS

Gas Sensor	Detects a wide range of gases (VOC, CO2 equivalent).
Pressure Sensor	Range 300 hPa to 1100 hPa
Humidity Sensor	0% to 100% relative humidity
Temperature Sensor	-40°C to +85°C
Interface	I2C

Table 7 BME680 Sensor Specifications

7.4 USAGE IN THE PROJECT

The BME680 sensor is used to monitor environmental conditions around the firefighting robot providing data on air quality, temperature, humidity and pressure.

8 FREERTOS

8.1 DESCRIPTION

FreeRTOS (Free Real-Time Operating System) is an open-source real-time operating system kernel designed for embedded devices It is widely used in microcontroller-based applications due to its simplicity, scalability, and reliability FreeRTOS is developed and maintained by Amazon Web Services (AWS) and has become a de facto standard for small, real-time embedded systems. (opc-ua-tsn-and-freertos, s.d.)

Figure 36 FreeRTOS

8.2 FreeRTOS architecture

FreeRTOS architecture is structured into layers that enable efficient operation in embedded systems At its core is the kernel which includes a preemptive scheduler for task management based on priorities alongside synchronization primitives like queues and semaphores for inter-task communication Above the kernel applications interact through APIs to create tasks manage synchronization and utilize timers The device driver layer interfaces with hardware peripherals providing an abstraction for hardware-specific operations while the hardware layer comprises the physical microcontroller and peripherals, This modular design ensures

FreeRTOS is lightweight, scalable, and adaptable across diverse embedded platforms catering to real-time requirements efficiently.

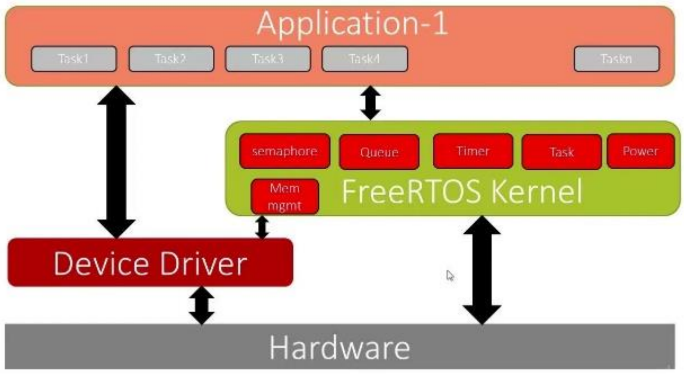

Figure 37 FreeRTOS Architecteur

8.3 USAGE IN THE PROJECT

FreeRTOS is used to manage the various tasks within the STM32 microcontroller, such as motor control, sensor data processing, and communication with the remote controller. It ensures that these tasks are performed in a timely and efficient manner.

9 PID CONTROLLER

9.1 DESCRIPTION

A PID (Proportional, Integral, Derivative) controller is an instrument used by control engineers to regulate temperature, flow, pressure, speed, and other process variables in industrial control systems. PID controllers use a control loop feedback mechanism to control process variables and are the most accurate and stable controller.

PID control is a well-established way of driving a system towards a target position or control parameters. It's practically ubiquitous as a means of controlling temperature and finds application in a myriad of chemical and scientific processes as well as automation. PID control keeps the actual output from a process as close to the target or set point output as possible.

9.2 PID ALGORITHM

A PID algorithm is a type of feedback controller whose output, or control variable, is based on three terms: proportional, integral, and derivative of the error signal. The error signal is the difference between the desired set point and the measured process variable. The PID controller adjusts the control inputs to minimize this error over time.

9.3 COMPONENTS OF PID ALGORITHM

9.3.1 PROPORTIONAL (P) TERM

- The proportional term produces an output that is proportional to the current error value.
- The proportional gain, k_p, determines the magnitude of the correction based on the error.
- Formula: $p(t) = k_p \cdot e(t)$
- **Effect: Increases the controller output proportional to the error, reducing the error quickly.**

9.3.2 INTEGRAL (I) TERM

- **The integral term produces an output based on the accumulation of past errors.**
- **The integral gain, k_i, determines the influence of the accumulated error.**
- **Formula:** $I(t) = k_i \int_0^t e(x)\,dx$
- **Effect: Eliminates residual steady-state error by integrating the error over time.**

9.3.3 DERIVATIVE (D) TERM

- **The derivative term produces an output based on the rate of change of the error.**
- **The derivative gain, k_d, determines the influence of the rate of change of the error.**
- **Formula:** $B(T) = k_d \frac{de(t)}{dt}$
- **Effect: Predicts future error based on its rate of change, improving system stability and response.**

9.3.4 COMBINED PID CONTROLLER FORMULA

The combined output of the PID controller is the sum of the proportional, integral, and derivative terms:

$$u(t) = k_p \cdot e(t) + k_i \int_0^t e(t)\,dt + k_d \frac{de(t)}{dt}$$

- $u(t)$ is the control output.
- $e(t)$ is the error at time t.
- k_p is the proportional gain.
- k_i is the integral gain.
- k_d is the derivative gain.

9.4 USAGE IN THE PORJECT

PID control is used to regulate the speed and position of the NEMA 23 motors and with The PID algorithm calculates the necessary adjustments to the motor inputs to achieve the desired movement and positioning.

10 JOYSTICK CONTROLLER

The joystick is a crucial control device for the remote-controlled fire hose system **"RoboTube"** developed in this project It allows firefighters to remotely control the direction and movement of the firefighting hose As the primary user interface the joystick offers intuitive and precise manipulation enabling firefighters to direct the hose to the exact point of the fire while staying at a safe distance from the flames and hazards.

Figure 38 Joystick Controller

11 CONCLUSION

This chapter provides a comprehensive overview of the electronic components used in the remote-controlled firefighting robot. Each component is described in detail, including its key features, usage in the project, and integration with other parts of the system. This information forms the foundation for understanding the electronic architecture and functionality of the firefighting robot

GENERAL CONCLUSION

Developing a robotic firefighting system represents a significant leap forward in enhancing the safety and efficiency of fire suppression operations. This innovative technology aims to create a remotely controlled extendable fire hose and intelligent nozzle (the head of the fire hose) that work to facilitate effective navigation through fires and extinguish them, minimizing the risks faced by firefighters. The effectiveness of this project and its integration of advanced electronic and mechanical components with real-time control systems highlight its potential to revolutionize firefighting by ensuring precise control, adaptability to various fire scenarios, and enhanced operational safety.

Looking ahead, future developments could see these robotic fire hoses installed in smart homes for early fire detection and rapid response, coupled with drones equipped with computer vision. Autonomous navigation, advanced sensors, modular design, and AI integration could further enhance system capabilities, allowing for predictive fire behavior analysis and optimized resource allocation. Additionally, with some modifications, this fire hose technology could be adapted for medical purposes, such as minimally invasive surgeries, offering new approaches to navigating within the human body for treatment or diagnostic procedures.

Continued research and development are essential to fully realize the potential of these robotic systems, contributing to safer, more efficient firefighting and innovative applications in other fields.

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