Water Spray Robot for Fire Fighters

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***Abstract*—There has been an increase in the number of fires nowadays and the risks associated with it have become a major concern. Therefore this paper proposes an intelligent firefighting robot that can handle the fires and provide aid to the firefighters. Motor drivers and gear motors enable mobility while the robot uses temperature and gas sensors to detect fires autonomously. Its water jet spray system works out put fires and an adjustable sprinkler allows for target water distribution. Furthermore, the robot utilizes ultrasonic sensors for finding and evading obstacles as it approaches fire sources. Although there are firefighting robot concepts; their acceptance is limited by some problems. The purpose of this study is to improve the technology used for firefighting robots and reduce the amount of risk and injuries firefighters experience.**

I. Introduction

Fire incidents happen often and at times, firefighters find it hard to rescue one during this crisis. A person cannot constantly monitor for unintentional fires as it will be a waste of resources. In situations of such nature, a firefighting robot comes into play. They will also enable a robot to remotely detect a fire. Such robots also come into high demand within fire-prone industries, for instance.

The purpose of this research is to explore the concept of an autonomous firefighter bot. Intelligent firefighting robots consist of the major parts of the firefighting movement system, firefighting water spray system, firefighting control system, and others. Every element works together to bring about the completion of the firefighting mission.

The proposed robot can use a temperature sensor and a gas sensor to detect fire after which it will extinguish it. Motor drivers and gear motors constitute it for controlling the movability of a robot. This water jet spray of the proposed robot will splash water. The sprinkler can be rotated in any direction it is directed. When traveling towards the fire, there may arise some hindrances whereby it uses ultrasonic sensors to sense any obstacle and move away from them.[1]

Many obstacles have caused the development of the concept of an intelligent robot for firefighting has not resulted in acceptance at a large scale level. Such fires are frequent and contribute to greater safety problems. With time, especially in highly congested towns, many oil and gas companies and underground constructions are being put up today. However, traditional fire extinguishers and fire extinguisher trains don't have the capacity to extinguish fire at such a high speed. In turn, firemen's lives can be at risk during firefighting operations. Therefore, one must conduct firefighting robot research to tackle this problem.

II. Literature Survey and Review

Several electrical devices were employed in controlling such firefighting robots in the past. But this reduces the command range for the firefighting robot. However, by applying these advanced processes, we would be able to build a robotic that can independently move itself up.[1]

Several studies have been carried out on robotic firefighting systems. Derie invented an autonomous robotic firefighter that operates entirely on its own using important sensor inputs which include ultraviolet (UV), infrared (IR) as well as other major hardware. Altaf, Akbar, and Ijaz also constructed and designed Autonomous Fire Fighting Robots. Its construction utilized a microcontroller as the robot controller and an LDR sensor.[2]

Fig. 1. Existing Firefighting Robot.

Xu et al carried out the design and implementation of a mobile robot remote fire alarm system comprising an object detection sensor, a fire detection unit, and an STC89C52 microcontroller. The object detection sensor was based on an infrared sensor, while the fire detection sensor utilized photoelectric, temperature, and fire sensors.

Cybersecurity was applied to develop and construct robotic firefighting systems by Bose. It comprised an object detection sensor, a temperature sensor, and a gas and flame detection sensor for fire detection. In several studies, an ultrasonic sensor was also used for detecting items in front of the robot as well as an object detection sensor and fire sensor. The previous study utilized an ultrasonic sensor that helped the robot identify the objects ahead of it.[2]

The current literature review also deals with other sensors such as thermal sensors, image sensors, and ultrasonic sensors among others. The integration of those varied sensory modalities will allow us to conceive an unstoppable, fireproof autonomous, spray water robot, capable of traversing through dangerous sites and quenching fires. This robot may change the way fire is fought by making it safer and less risky for a person to engage in the suppression process.

III. Proposed Solution

This was a project that involved an autonomous wheeled robot to move from one site to another. The design of the robot used two AC induction motors and six wheels. Because of the work system, the robot was able to turn right, left, or retreat, depending on the obstacle in its way.

Enter the fearless robot firefighter! The autonomous machine attacks fire directly, moving through burning areas and using precise water spray to extinguish flames. By taking the place of firefighters in risky situations, it allows them to focus on rescue efforts and overall fire control. This innovation leads to safer and effective fire response hence saving lives and property.[2]

The robot features a fire control system, fire sprinklers, and a mobility system with a fighting fire function. Each of those factors works as a whole to ensure that all the efforts are coordinated, and the firefighting mission is over.

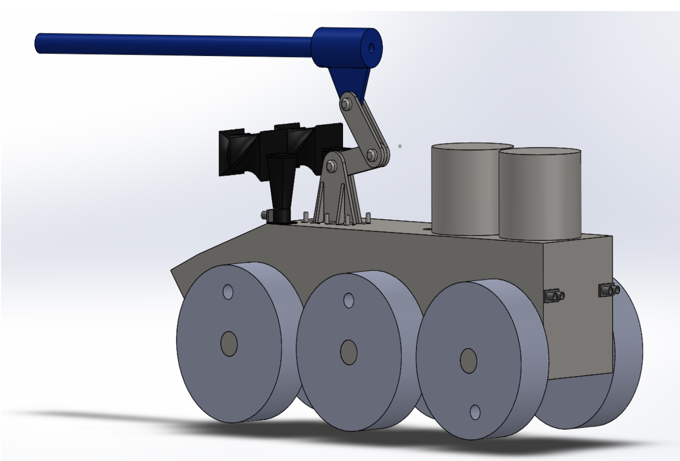

Fig. 2. Proposed model for firefighting robot .

The body of the robot is made from a fire-resistant material capable of withstanding high temperatures, thus acting as a shield from the heat of the fire against the robot and its electrical components. Such a device will be located on top of a more flexible robot body simulating the movement of upper limbs in humans. Additionally, there are cameras, sensors, power supply systems, and other elements that make the robot body as an accessory for making the robot capable of handling the firefighting mission. The robot receives water from an external source to combat fires.

The major component of a robot is the robot body, which performs the robot's functions. They are reasonably safe, and the operator can control speed as he likes. This could cross a terrain sloping by some degrees in an environment featuring various types of fires. The internal automobile body hosts a battery, which powers up the entire robot's power source. The cameras are placed behind the firearm and on the middle part of the machine's body to relay information to the ops screen regarding the specific incident of a fire, and also the working condition of the firearm itself. There is a camera placed on top of the pan-tilt which swivels through 360 degrees, this allows for viewing of the whole scene around the inferno.[3]

The firing arm consists of a jib, boom, middle boom, and support. Included in these are a water-cutting cannon and transmission gearing systems fixed within the little arm. It is also useful with the water-cutting cannon which adjusts for different operating faces and directs high-pressure water in the fire direction for fighting a fire. The fire control arm can be mounted to this flexible structure, as well as have the capability to act like a fire control device.

IV. Functional Aspects and System Overview

The functional structure of an intelligent firefighting robot can be divided into three main components: core components, mobility system, and firefighting system.

A. *Core components of an intelligent firefighting robot*

The essential parts that compose an intelligent firefighting robot form the foundation for its clever and independent work. These parts work together to give the robot the necessary abilities to find, locate and put out fires well.[3]

- Central Processing Unit (CPU)

The Central Processing Unit (CPU) acts as the mind of the intelligent firefighting robot. This powerful small computer is accountable for dealing with the huge amounts of data made by the robot's sensors, like thermal images, smoke levels, and environmental conditions. It also plays an important role in making real-time choices about the robot's actions, like navigating through intricate places, avoiding obstacles, and directing the firefighting system. The CPU's ability to analyze sensor data and develop smart responses is crucial for the robot to work well in dynamic and hazardous firefighting situations.

- Power Supply Unit (PSU)

The core of the intelligent firefighting robot's electrical architecture is the power supply unit. It transforms and stabilizes the electricity from the robot's energy cells, guaranteeing that all parts receive the requisite voltage and current to perform as intended. The power supply must be engineered to handle the high energy demands of the robot's motors, detectors, and actuators, while also providing dependable and consistent power for prolonged operational periods. In critical firefighting situations, a robust power source is fundamental for preserving the robot's capabilities and safeguarding the firefighters and property.[4]

- Communication Unit

The communication unit allows seamless communication between the intelligent fire-fighting robot and exterior devices, like a central control station, other robots, or human operators. This networking is crucial for coordinating firefighting efforts, giving live information and status updates, and enabling far-off control of the robot in critical circumstances. The communication module may utilize numerous technologies, for example, wireless radio, Wi-Fi, or mobile systems, relying upon the particular necessities of the fire-protecting condition. Effective communication is basic for amplifying the robot's effect and guaranteeing its coordination with current firefighting methodologies.

B. *Mobility system of an intelligent firefighting robot*

- Drive systems

The drive system is the heart of an intelligent mobile firefighting robot, allowing the robot to maneuver in a variety of challenging environments. It is a combination of motors, wheels, or tracks that convert electricity to supply it will be a mechanical mover, moving the robot forward, backward, or sideways. The drive system must be able to withstand tough firefighting tasks, including navigating rough terrain, overcoming obstacles, and moving has stand firm in dangerous situations.[4]

- Navigation System

The guidance system acts as a navigation system for an intelligent firefighting robot, enabling it to locate and plan its route to the fire source It uses a number of sensors including GPS modules, inertial measurement units (IMUs);, along with odometers to collect real-time data of robot position, orientation and speed. These data are then processed by sophisticated systems to simulate the environment further, allowing the robot to maneuver toward the fire, avoiding obstacles and optimizing its path. Accuracy of the navigation system is important to ensure that a robot reaches the fire quickly and efficiently, reducing property damage and saving lives.

- Integration of Drive systems with Navigation systems

Seamless integration of drive and navigation systems is essential for the mobility of intelligent firefighting robots. The guidance system provides the robot with knowledge of where to go, while the driving system translates that knowledge into physical movement. The two systems must work in concert, and the navigation system constantly updates the drive system to the desired path of the robot and drives it.[5]

- Advanced Mobility Features

Intelligent firefighting robots incorporate more advanced features that allow them to run and maneuver in complex firefighting situations These features include:
Adaptive Traction Control: Automatically adjusts motor power delivery to maintain traction on uneven or slippery surfaces.
Obstacle Avoidance: Enable robots to detect and avoid obstacles such as debris, building hazards, or other firefighting equipment.
Multidirectional Movement Capability: Allow the robot to move in multiple directions to maximize its maneuverability in tight environments, including forward, backward, or even rotating in place.
Stair lift: Allows the robot to ascend or descend stairs, extending its functionality in multi-story buildings.
These advanced firefighting features further expand the capabilities of intelligent fire-aware robots.[6]

C. *Firefighting system of an intelligent firefighting robot*

- Fire Detection System

Fire detection systems play an important role in the ability of fire-extinguishing robots to locate and extinguish a fire. Several sensors are used to collect information about the presence, location, and severity of fires. These sensors include:
Thermal sensors: detect signs of heat, allowing the robot to locate the flame even in smoke-filled environments.
Image sensors: capture visual data, which can be analyzed to identify fire patterns and smoke patterns.
Radiation detectors: detect the presence of smoke and other hazardous gases, providing additional situational awareness.
Sonar sensor: produces sound waves that can be used to detect obstacles and map the environment, including potential hazards such as debris or structural damage.

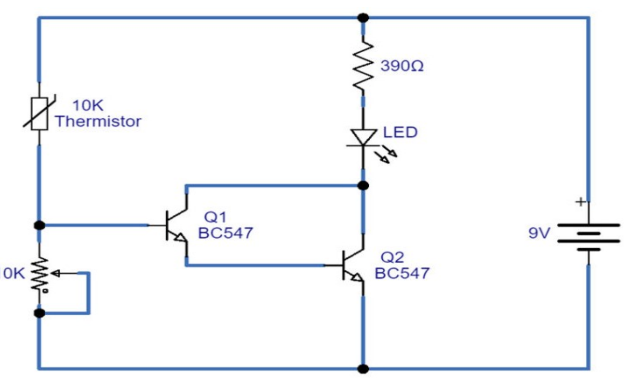

Fig. 3. Temperature sensor circuit.

Data from the fire detection system are integrated and analyzed by the robot's central processing unit (CPU) to determine the location, size, and potential spread of fire. This information is important for the robot to make appropriate path decisions for his approach to firefighting policy.[6]

- Water Spraying System

Sprinklers are the primary firefighting devices of intelligent robotic firefighters. It consists of a tank, a pump, and a sprayer that together produce a controlled amount of water or vapor for extinguishing fires. The system must be robust and effective, capable of delivering a powerful spray that can reach the source of the fire and contain the flames.

Water Tank: Stores water or fire extinguishing foam. The capacity of the tank must be able to handle the size and scale of fire.

Pump: Provides the necessary pressure to push water or steam into the fire. The capacity of the pump must match the mobility and firefighting capabilities of the robot.

Spray nozzle: Controls the direction and intensity of the liquid or foam spray. The nozzle design can be modified to accommodate spraying for different fire conditions.

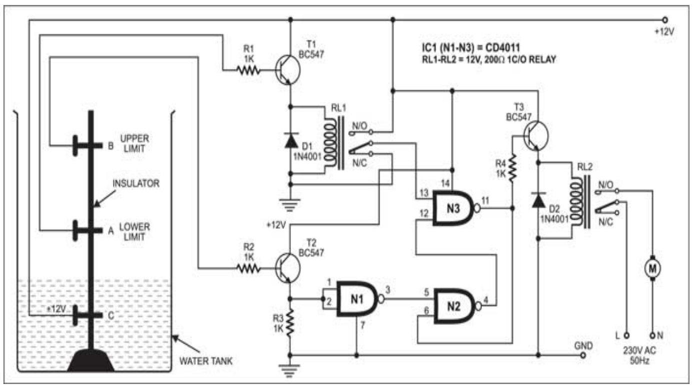

Fig. 4. Automatic pump circuit.

The robot's CPU, which receives real-time data from the fire detection system, controls the sprinkler system. Using this information, the robot can adjust the spray pattern, intensity, and duration based on the fire characteristics and the location of the robot.[7]

- Integration of Fire Detection and Water Spraying Systems

Combining fire detection with water sprinklers is essential to improve the effectiveness of intelligent firefighting robots. The fire detection system provides the robot with the necessary information to locate the fire, while the sprinkler system provides the extinguishing features Both systems must operate collectively, the fire detection system keeps updates on fire conditions and the water sprinkler system optimizes its operation accordingly hence reducing the water usage and improving the extinguishing efficiency.

The addition of a sonar sensor further enhances the robot's ability to detect and map obstacles. This allows the robot to safely navigate a hazardous area, avoiding obstacles that could interfere with its firefighting efforts or pose a danger to itself or others.[8]

In summary, a firefighting system consisting of intelligent robotic fire extinguishers is key to robots being able to enter, locate, and extinguish fires efficiently using advanced sensors, water sprinklers, and sophisticated control algorithms allowing the robot to operate autonomously in dynamic and challenging firefighting scenarios.

V. Simulations and Results

A. Fire detection system integrated with temperature detection and smoke detection

The fire detection system of the firefighting robot design comprised of temperature and smoke sensors offers a robust and reliable approach to establishing protection against potential fires.

1) Benefits of using two types of sensors

- *Increased accuracy*: Coupling data from two different types of sensors reduces false alarms and missed fires.
- *Improved sensitivity*: Sensitivity elevates the accuracy of the data fetched by sensors.
- *Robustness*: This system can detect fires even if one sensor is malfunctioning.
- *Adaptability*: Thresholds for both sensors can be adjusted based on the environmental conditions and typical conditions of a somewhat hazardous fire.

2) The fire detection system of the robot comprises four main important components.

- ***Temperature sensor***: Monitors ambient temperature and triggers an alarm when the temperature exceeds a predetermined threshold value.
- ***Smoke sensor***: Detects smoke particles in the atmosphere and activates an alarm when the smoke level surpasses the predetermined threshold.
- ***Control unit***: Processes data from both sensors, analyzes it based on pre-defined algorithms, triggers an alarm, and activates response mechanisms like water pump activation.
- ***Power source***: Provides stable power for the system's operation.

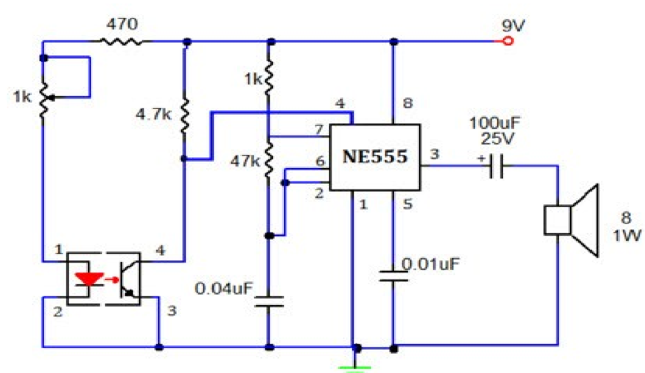

Fig. 5. Smoke detector circuit.

3) Top Temperature and Smoke Sensors in the Market

- Temperature Sensors:

Resistance Temperature Detectors (RTDs): Highly accurate and stable for a wide temperature range. Ideal for industrial applications.

Thermistors: Rapid response time and sensitivity to varying temperatures. Suitable for consumer electronics and monitoring systems.

Infrared (IR) Thermometers: Non-contact measurement for hazardous environments or moving objects. Ideal for fire detection in robots and drones.

- Smoke Sensors:

Photoelectric: Sensitive to smoke particles from smoldering fires. Ideal for residential buildings. Ionization: Detects smaller smoke particles from flaming fires. Suitable for kitchens and areas prone to grease fires.

Dual Sensor: Combines both photoelectric and ionization technologies for increased accuracy and reduced false alarms. It is a popular choice for general fire protection.

Considering the above sensors, using IR thermometers as smoke sensors and dual sensors for smoke sensors will be the best choice for the designed firefighting robot. A **Matlab code** has been developed to represent the foundational framework. However, note that the code uses **random values for smoke and temperature values**. More sophisticated code should be developed by integrating temperature and smoke sensors for the real-world scenario.

```
>> flame_smoke_and_temperature_detection
Time: 0s - Smoke: 81.47, Temperature: 75.29
Fire detected!
Time: 20s - Smoke: 12.70, Temperature: 75.67
Fire detected!
Time: 40s - Smoke: 63.24, Temperature: 34.88
Fire detected!
Time: 60s - Smoke: 27.85, Temperature: 57.34
Fire detected!
Time: 80s - Smoke: 95.75, Temperature: 78.24
Fire detected!
Time: 100s - Smoke: 15.76, Temperature: 78.53
Fire detected!
Time: 120s - Smoke: 95.72, Temperature: 54.27
Fire detected!
>>
```

Fig. 6. Data generated in the control unit.

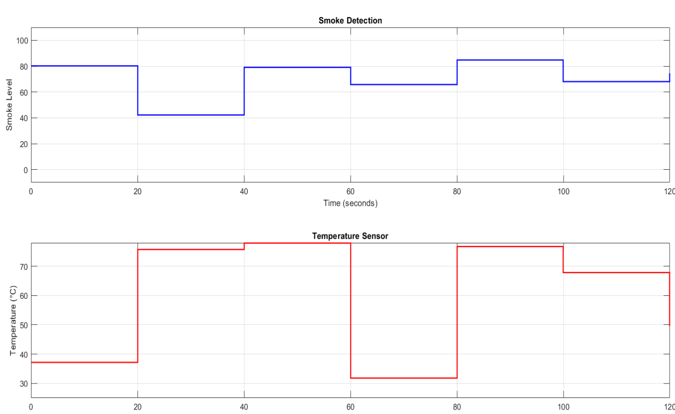

Fig. 7. Plots of Smoke and Temperature over time.

The First diagram represents how commands are generated in the control system which is crucial for all controls and the second diagram represents plots of smoke and temperature values detected by relevant sensors over time. Remember, this is a trial case that uses random smoke and temperature because it is unable to implement a smoke and a temperature in a simulation. It should be calculated by using external sensors and related algorithms. The presented code provides a foundational framework for fire detection, but several adjustments are needed for a real-world scenario such as,

- **Sensor Integration**

Utilize appropriate sensors for smoke and temperature flame detection. Ensure accurate sensor readings by performing calibration and validation. Further, implement noise filtering and signal processing techniques to handle sensor noise and improve the reliability of real-time data.

- **Data Acquisition and Processing**

Develop a data acquisition system to collect sensor data in real time, including communication protocols and data processing algorithms. Additionally, use advanced algorithms to analyze sensor data streams for identifying fire patterns and triggering alerts efficiently.

Building a real-world fire detection system requires expertise in electronics, programming, control systems, and sensor technology. Collaborate with engineers and experts for successful implementation and ensure compliance with safety regulations. However, there is a possibility of outputting false alarms. To eliminate this, we use a camera that detects flames by using a specific image processing algorithm. It will be discussed in the next part.

B. *Cameras for further detection*

Once a fire is detected by the fire-detecting system, then the camera starts its task. The camera has the ability of 360-degree rotation. It will rotate and check whether there is a fire or not using a specific image processing methodology. If the system detects a fire-like condition, it will further persuade the system that, the fire signal from the fire detection system, isn't fake. Then the system reacts quickly by enabling its fire extinguishing options (i.e. the automatic water pump activation) to extinguish the fire. Here, is a further overview of this methodology:

1) Suitable cameras available in the market for fire detection tasks.

Considering the general aspects of fire detection in a robotic context, utilizing a thermal camera is often a good option. Thermal cameras are designed to identify infrared radiation, making it possible to identify heat sources associated with fires effectively. Here are some better cameras available in the market which is suitable for a fire detection process.

- **FLIR Lepton Series**

The FLIR Lepton series is a popular choice for thermal imaging. It can be in different resolutions, and it's compact, making it suitable for integration into robotics applications.

- **FLIR Boson Series**

The FLIR Boson series offers higher resolutions and more advanced features. It provides thermal imaging capabilities with options for diverse resolutions, frame rates, and sensitivity levels.

- **Raspberry Pi High-Quality Camera with IR Filter**

It is a visible spectrum camera with the ability to add an infrared (IR) filter, you could consider using the Raspberry Pi High-Quality Camera along with an IR filter. This allows the camera to capture both visible light and infrared information, which can be useful for fire detection.

- **Point Grey/FLIR USB3 Vision Cameras**

Point Grey (now part of FLIR) produces a range of USB3 Vision cameras that are widely used in robotics and computer vision applications. These cameras come in various resolutions and frame rates, providing flexibility based on your specific requirements.

2) How to choose a suitable camera for this task?

Choosing the most suitable camera for fire detection for the firefighting robot depends on various factors such as lighting conditions, budget constraints, environment, and the specific requirements of the task. Here are some general considerations and specifications that have to be taken into account when choosing a camera for fire detection.

- **Resolution**

Higher-resolution cameras often capture more details, which is crucial for precisely identifying fires. However, high-resolution images/videos require higher computational power. Hence, a balanced mode between these two aspects is a must.

- **Frame Rate**

A higher frame rate can be advantageous for real-time applications, allowing the system to respond immediately according to the changes in conditions in the surroundings.

- **Spectral Sensitivity**

Choose a camera with good sensitivity to the spectral range associated with fire. Typically, the visible and infrared spectral range. Infrared sensitivity is useful for detecting heat sources.

- **Dynamic Range**

Cameras with a wide dynamic range can handle scenes with varying levels of brightness, such as those encountered in fire detection scenarios. For our design, we are using a Raspberry Pi High-Quality Camera with IR Filter.

3) The methodology we are using for the fire-fighting robot camera.

- **Image Acquisition**

Since the fire-fighting robot is involved in the operation of eliminating fire, the two cameras mounted in our design are in turn on stage all the time. In addition, this camera has a 3600 rotation ability for better capture of the surroundings. Capture images using this camera which is mounted on the fire-fighting robot. (As in the diagram of our final design)

- **Preprocessing**

Preprocess the captured images if needed. It is optional. Preprocessing is commonly used for noise reduction, resizing, etc.

Fig. 8. Captured image

- **Grayscale Conversion**

Convert the captured images to grayscale. After conversion, fire-like areas is implemented in white color while all other areas are represented in black color. This approach simplifies the image to a single channel, making it easier for the hardware of the robot to work with.

Fig. 9. Processed image

- **Utilizing a threshold value**

Apply a threshold to the grayscale image. This involves setting a pixel intensity. We must define a special threshold value that is based on the pixel intensity of a fire which assists the fire-fighting robot to identify the fire condition. (Whether it is a large fire or not) When the intensity of the processed image exceeds the threshold value, i.e. a sufficiently large and fire-like region is detected, triggers the desired actions of our fire-fighting robot design. (e.g.: alerting, pump activation, arm and vehicle controls, etc.)

C. ***Motors of the vehicle to move forward***

For the movement of the vehicle, according to our design, six wheels are integrated into the vehicle. Choosing the right motor to drive the wheels of a heavy-duty vehicle on factors such as:

1) ***Payload capacity***: The design comprises various parts such as rigid tanks like metallic vehicle bodies, large wheels, cameras, sensors, etc. On top of that, the designed vehicles are designed to contain large amounts of water as well. Owing to the heaviness of the overall design with a large amount of water, the motors should have an enormous strength to rotate wheels to provide traction and propel the vehicle forward.

2) ***Terrain***: Operating on rough terrain requires a motor with high torque and good off-road capabilities to accomplish the mission.

A three-phase induction motor is a good option for heavy-duty vehicles, translating electrical energy into powerful torque that propels these massive machines. In our design, we use two for our six wheels. In this case, each motor drives a separate axle, providing independent power and control to each set of three wheels. This configuration offers several advantages, including improved traction, handling, and off-road capability.

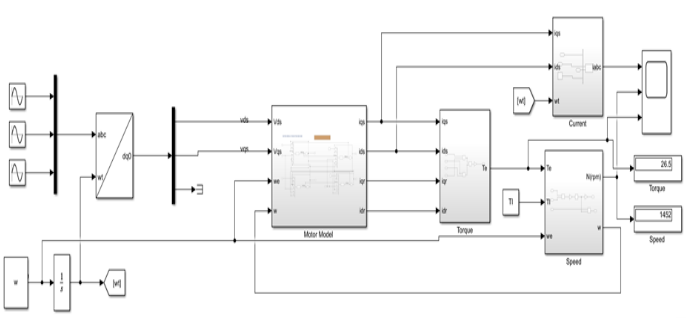

Fig. 10. Simulink model for 3-phase AC induction motor

3) ***Mechanism***

An electric battery stores the electrical energy needed to power the vehicle. This energy is then supplied to the inverter, a crucial component that converts the direct current (DC) from the battery to alternating current (AC). The inverter plays a senior role in controlling the speed and torque of the motor by adjusting the voltage of the supplied AC and the frequency. This allows for smooth and efficient operation under diverse driving conditions. The converted AC flows through the stator windings, strategically arranged within the motor. These windings generate a rotating magnetic field within the stator. Inside the stator lies the rotor, which is a conductive core made up of aluminum or copper.

As the rotating magnetic field sweeps past the rotor, it induces currents within its conductive bars. These induced currents affect to create their magnetic field. The interaction between the rotating magnetic field of the stator and the induced magnetic field of the rotor produces torque. This torque acts on the rotor, making it possible to rotate in the same direction as the stator's field. The rotating shaft of the motor transmits power to the drivetrain, which is a complex system of gears and differentials. This drivetrain distributes the generated torque to the wheels, eventually driving them and moving the heavy-duty vehicle forward. Several benefits can be obtained by integrating this type of motor to the fire-fighting robot such as,

- **Efficiency and Durability**

They are highly efficient and require minimal maintenance due to the lack of brushes, slip rings, or commutators.

- **Robustness**

They are extremely robust, withstanding overloads, voltage fluctuations, and operating conditions that may damage other types of motors.

- **Cost-Effective**

They have a low cost of production compared to other motors with similar capacity.

- **High Torque**

They provide a high starting torque, which is beneficial in driving wheels in a heavy-duty vehicle.

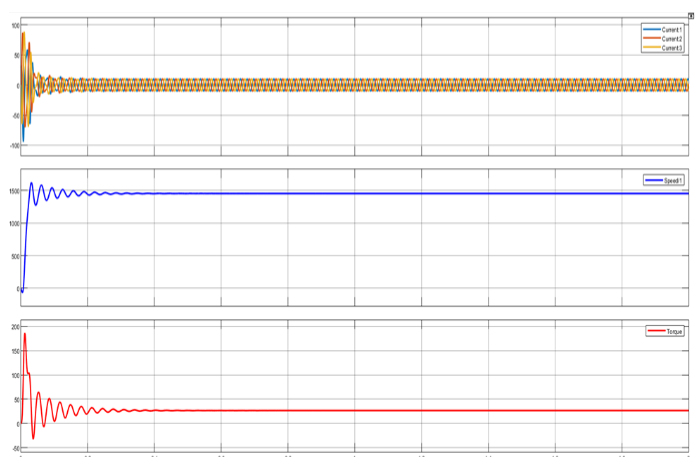

Fig. 11. Plots for speed and torque of the motor

The above plots represent 3-phase currents in A, speed in RPM, and Torque with kN overtime respectively. According to the plots, the motor generated a high starting torque around 180 kN mark which is vital for the heavy-duty fire fighting robot vehicle. Moreover, both speed and torque become steady in a very short period. This is beneficial to control the vehicle with ease.

D. ***Obstacles detection***

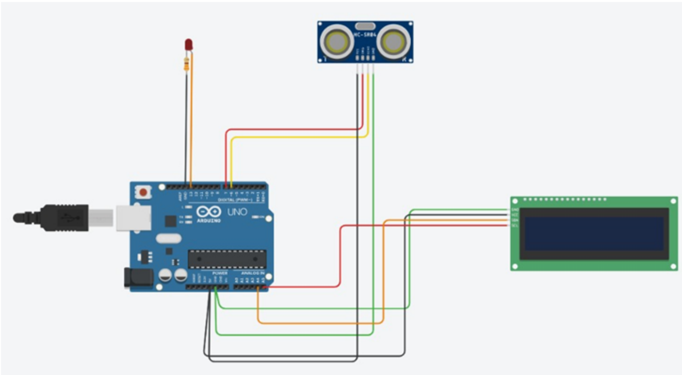

Fig. 12. Obstacles detection system design

Link of the tinkercad design :
https://www.tinkercad.com/things/ehQbU8Bvu01-ingenious-uusam-jaban

The image shows the designed obstacle detection system of the firefighting robot. The circuit comprises with an Arduino board, an ultrasonic sensor, and an LCD. Additionally, a 330-ohm resistor and an LED have been integrated into the design. The ultrasonic sensor is used to calculate the distance of an object from the sensor and the LCD is used to show the distance calculated.

The ultrasonic sensor has four pins: VCC, GND, Echo, and Trig. VCC is connected to the 5V pin of the Arduino board, GND is connected to the GND pin of the Arduino board, Echo is connected to digital pin 6 on the Arduino board and Trig is connected to digital pin 7 of the Arduino board.

- **Working process**

The Arduino board sends a pulse to the trigger pin on the ultrasonic sensor. This pulse triggers the sensor to emit an ultrasonic sound wave. The emitted ultrasonic sound wave travels through the air until it hits an obstacle. When the sound wave hits an object, it is reflected to the ultrasonic sensor. The ultrasonic sensor detects the reflected sound wave and sends a pulse to the Echo pin on the Arduino board. The time between the pulse sent to the Trig pin and the pulse received at the Echo pin is equal to the time it took for the sound wave to travel to the obstacle and back. The Arduino board calculates the distance to the object based on the time it took for the sound wave to travel to the object and back. The Arduino board displays the distance to the object on the LCD. For the simulation, a threshold distance of 100cm is applied.

The green dot in the figure below represents the place where the obstacle is located, and the green area shows the region covered by the ultrasonic sensor. Ultrasonic sensor signal will do its task appropriately in that region. As in the diagram, when the distance for the obstacle is above 100cm, it does not light up the LED. By detecting that data from the obstacle detection system and identifying that there is not any obstacle nearby. Moreover, the display shows the value of the distance as well. (In the case below, the value is 153cm)

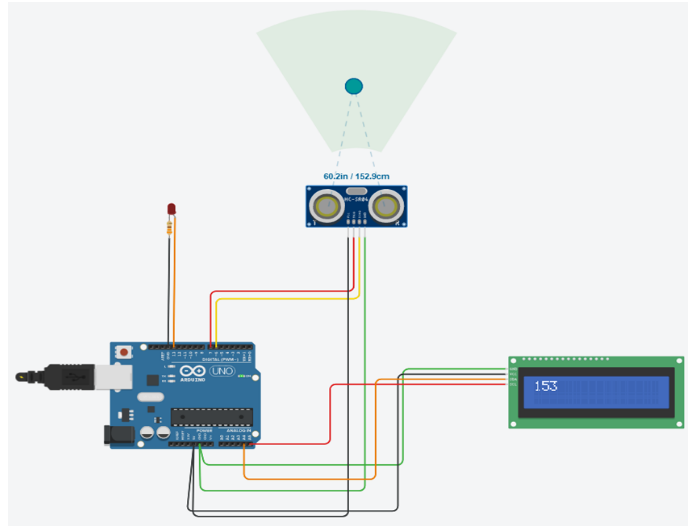

Fig. 13. Obstacle detection at a distance above 100 cm

As in the figure below, when an object detected which is at a distance below 100 cm, then the light that we placed on the Arduino board lights up. Then the system understands there is an obstacle nearby and the system will control the vehicle movements (Left, right, front, back) to evade the obstacle. However, in the real-world scenario, the threshold value should be established by considering some factors such as the size of the vehicle and braking system capabilities of the vehicle.

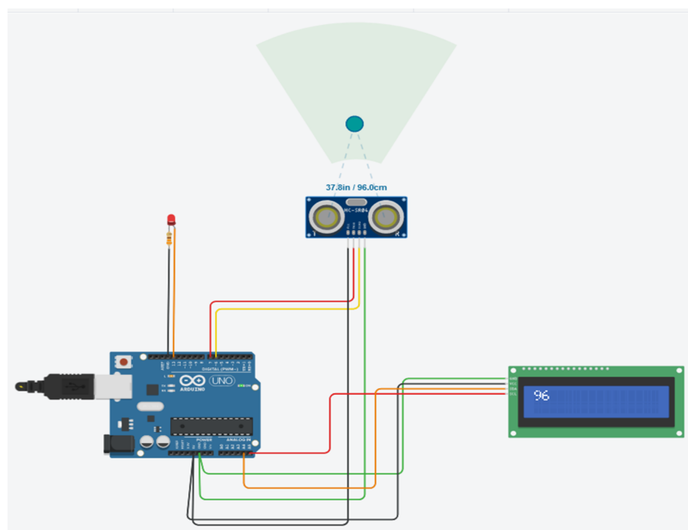

Fig. 14. Obstacle detection at a distance below 100 cm

The code mentioned below is used to control the above ultrasonic sensor. In the real-world scenario, programmed Arduino board with setting up the apparatus in the figure, the obstacle detection task can be achieved.

```
// C++ code
//
#include <Adafruit_LiquidCrystal.h>

int ultrasonic = 0;

long readUltrasonicDistance(int triggerPin, int echoPin)
{
  pinMode(triggerPin, OUTPUT);  // Clear the trigger
  digitalWrite(triggerPin, LOW);
  delayMicroseconds(2);
  // Sets the trigger pin to HIGH state for 10 microseconds
  digitalWrite(triggerPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(triggerPin, LOW);
  pinMode(echoPin, INPUT);
  // Reads the echo pin, and returns the sound wave travel time in
  return pulseIn(echoPin, HIGH);
}

Adafruit_LiquidCrystal lcd_1(0);

void setup()
{
  Serial.begin(9600);
  lcd_1.begin(16, 2);
  pinMode(13, OUTPUT);
}

void loop()
{
  ultrasonic = 0.01723 * readUltrasonicDistance(7, 6);
  Serial.println(ultrasonic);
  lcd_1.print(ultrasonic);
  delay(500); // Wait for 500 millisecond(s)
  lcd_1.clear();
  if (ultrasonic < 100) {
    digitalWrite(13, HIGH);
  } else {
    digitalWrite(13, LOW);
  }
}
```

Fig. 15. Code for object detection

E. *Robotic Arm for spraying Water*

In the face of escalating challenges in firefighting scenarios, there is a growing need for advanced technology to augment the capabilities of firefighters. This report delves into the design and implementation of a robotic arm specialized in releasing water, integrating cutting-edge sensors to optimize water deployment, enhance firefighting efficiency, and ensure the safety of emergency responders.

Conventional firefighting methods involve manual deployment of water, presenting limitations in terms of reach and precision. This report explores the development of a robotic arm designed to precisely release water in strategic locations, addressing critical firefighting needs.

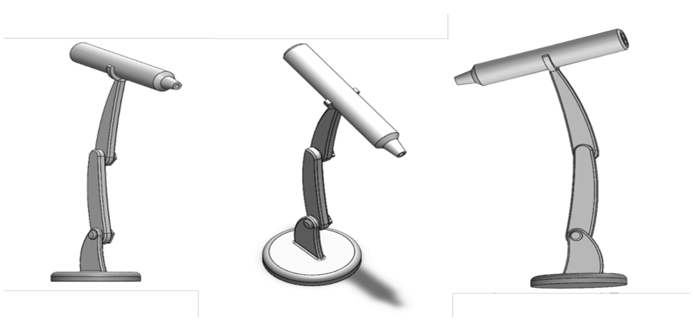

Fig. 16. Robot arm

The primary objectives of the robotic arm are to improve the accuracy and efficiency of water deployment, reduce risks to firefighters, and provide real-time data through sensor integration.

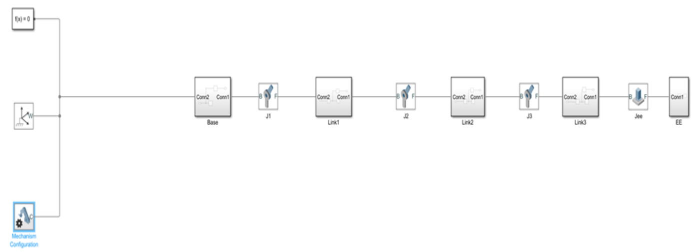

Fig. 17. Sample Design done by MATLAB Simulink for Motion of Robotic Arm

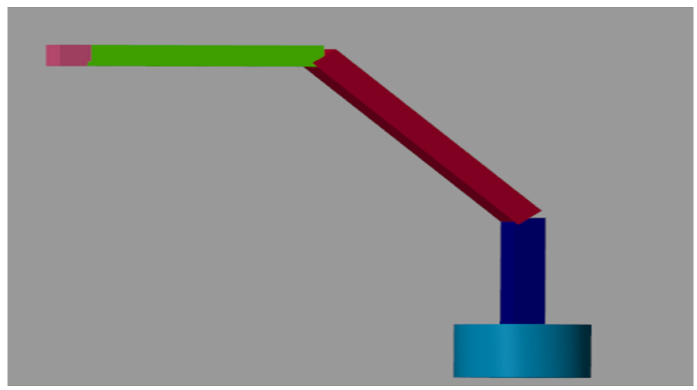

Fig. 18. simulink model

- Control and Communication of Arm

The robotic arm is remotely controlled by firefighters through a secure communication system. Sensor data is continuously transmitted to the control center, providing real-time insights into the firefighting environment and allowing for dynamic adjustments. Sample automated motion occurred due to a random input signal:

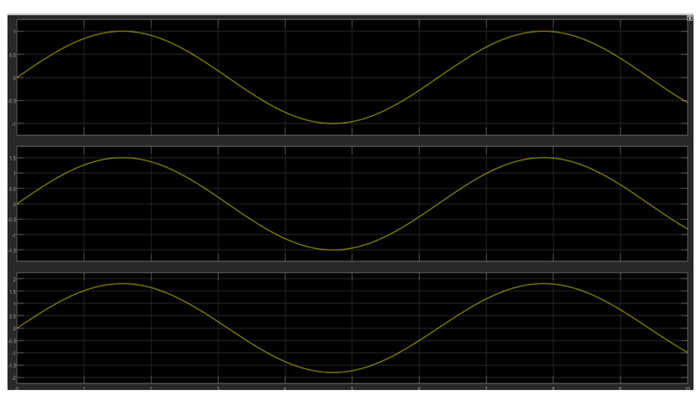

Fig. 19. Input plots for three joints

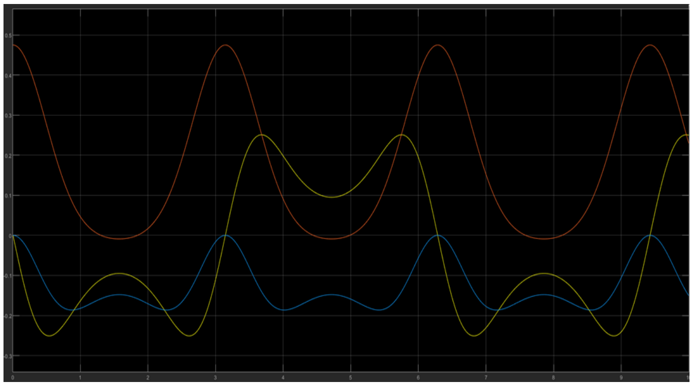

Fig. 20. Output plots through(XYZ axis)

- Sensor Integration:

The robotic arm incorporates a range of sensors designed to enhance its functionality:

1)Temperature and Infrared Sensors:

Purpose: Detects heat sources, enabling the robotic arm to target areas with high temperatures effectively.

Benefits: Enhances precision in water deployment, optimizing firefighting efforts.

2)Optical and Vision Sensors:

Purpose: Provides visual feedback to identify fire locations and assess the effectiveness of water deployment.

Benefits: Enables real-time monitoring and adjustment of the robotic arm's actions.

3)Pressure and Flow Rate Sensors:

Purpose: Monitors water pressure and flow rates during deployment.

Benefits: Ensures optimal use of water resources and allows for adjustments based on specific firefighting requirements.

4)Environmental Sensors:

Purpose: Detects wind direction and speed to optimize water spray patterns.

Benefits: Improves the precision of water release, minimizing water wastage and maximizing firefighting impact.

Benefits of the robot arm :

Precision Water Deployment: Sensors enhance the accuracy of water release, targeting specific areas with precision.

Enhanced Safety: Minimizes the exposure of firefighters to dangerous environments by automating water deployment tasks.

Real-time Monitoring: Sensors provide critical data for informed decision-making during firefighting operations.

Further developments :

Challenges include the integration of sensors in dynamic and unpredictable fire scenarios. Future developments may focus on machine learning algorithms for adaptive response and additional sensors for improved environmental awareness.

VI. CONCLUSION

A Technological Guardian: Real-Time Firefighting Robot

Imagine a fearless machine, navigating dangerous terrain and putting out fires with precision and unwavering ability. This vision will become a reality with real-time underground firefighting robots. Equipped with powerful sprinklers and an intelligent control system, the robot tackles fire emergencies head-on, allowing firefighters to operate remotely and clean up on the dangerous side.

Its success is based on its three pillars: a remotely controlled brain that adjusts sprinklers based on real-time data, powerful sprinklers with excellent fire resistance, and programming dense mobility that guides even the most difficult terrain.[9]

Beyond human limitations, this robot ventures into hazardous areas, collects vital information, and sends it back to firefighters to make appropriate decisions Real-time tracking capabilities ensure fire suppression completely and continuously monitor the scene, ensuring the safety of personnel and property.

This amazing robot is not just a machine; It's a sentinel and a beacon of hope for future fire safety. The ability to automate hazardous tasks paves the way for safer and more efficient fire response. Imagine a world where firefighters can focus on rescue efforts knowing they have a fearless angel at their side - a future promised by real-time firefighting robots.

VII. ACKNOWLEDGEMENTS AND CONTRIBUTIONS

The modeling, design, and simulation parts required for this project, such as; water spraying robot arm modeling, design and its simulation, and Sonar sensor design and simulation were done by **BANDARA M.M.P.S.S. 210065N**. Robot motor simulation, input image processing, and the final design of the proposed firefighting robot were done by **ATHUKORALA N.C. 210056M**. The rest of the parts such as fire fire-detecting system with temperature and smoke detection, robot wheel rotation simulation (provided as additional material), and compiling the final project report in LATEX were done by **ARJUN P. 210052X**. Obtaining data for the literature review, functional aspects, and system overview was a collective effort of all three group members.

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