Design and Development of a Smart F ire Fighting Robot for Hazardous Environment Applications

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Abstract: Fire incidents can be very serious and result in substantial loss of life and property, particularly in industrial, domestic and public buildings. An autonomous firefighting robot is developed to enhance the safety and minimize the risks for firefighters. The robot has a flame sensor and temperature sensor to detect fire, a microcontroller for processing the detected fire information, and a DC motor to drive the robot towards fire. Then it will switch on a water pump or fire extinguishing system to put out the fire. It has obstacle detection sensors that allow it to safely navigate in dangerous environments. It is compact, inexpensive and can be used in multiple locations, with rapid response with minimal human exposure. Overall, it showcases the effective use of robotics and embedded systems in fire safety and disaster management.

Keywords: Firefighting robot; Arduino; Flame sensor; IoT; Automation; Embedded system.

1. Introduction

With the ever-increasing technology, the developments are increasing in the face of the situations that cause human life. Every day, the robot industry emerges as a model that is produced as an alternative to the human element in a new branch. Flying, robots, wheeled robots legged robots, humanoid robots, and underwater robots are just some of them. The growing world population is bringing involuntary problems together. Fires are among the most important of these problems. The robot industry has a lot of work in this area. Some of these are fixed mobile robots with different features, which are equipped with different sensors that detect before the fire is out, mobile rescue robots as fire search and rescue equipment, mobile locating robots used for fire detection, fire extinguishing robots in many different models designed to assist firefighters in the fire.

An embedded system is one kind of computer system mainly designed to perform several tasks like accessing, processing, and store, and also controlling the data in various electronics-based systems. Embedded systems are a combination of hardware and software where software is usually known as firmware that is embedded into the hardware. Embedded systems support to make the work more perfect and convenient. The applications of embedded systems mainly involve in our real-life for several devices like microwaves, calculators, TV remote control, home security, neighborhood traffic control systems, etc.

Fire accidents pose a serious threat to human life, property, and the environment. In many situations such as industrial fires, residential fires, or hazardous environments, it becomes extremely dangerous for firefighters to enter and control the fire manually. Traditional firefighting methods often expose humans to high temperatures, toxic gases, and the risk of explosions. Therefore, there is a need to design and develop an automated firefighting robot that can detect fire, navigate towards the source, and extinguish it without human intervention. The robot will be able to operate in dangerous and inaccessible places, to save human effort and improve safety. The primary challenge is to develop a system that can use sensors, control systems and extinguishing equipment to provide efficient, reliable and fast response.

Fire accidents expose firefighters to extreme heat, smoke, and toxic gases. A firefighting robot helps reduce direct human involvement and minimizes risk to life. Certain fire situations (chemical plants, gas leaks, electrical fires) are too dangerous for humans. Robots can safely operate in such high-risk areas. Early detection of fire using sensors allows the robot to respond quickly, helping to control fires before they spread. With the advancement of automation, robots can perform firefighting tasks efficiently using sensors, microcontrollers, and intelligent control systems. Quick action by robots can prevent the spread of fire, thereby reducing damage to buildings, industries, and valuable assets. Unlike humans, robots can work continuously without fatigue, making them suitable for long-duration firefighting tasks. Although initial setup cost is high, robots reduce long-term expenses related to manpower, safety equipment, and risk management. Firefighting robots can be used in industries, warehouses, homes, and public places.

Developed an intelligent firefighting tank robot. Materials like acrylic, plastic, aluminum, and iron are used to make the robot. The tank robot is consisting of components like two servo motors, a thermal array sensor, two DC motors, a flame detector, an ultrasonic sensor, IR and phototransistors, sound activation circuit, and a micro- switch sensor. The goal of the paper is to search the prescribed area find the fire and extinguish it. The robot is activated by using a DTMF transmitter and receiver [1-5]. Developed a firefighting robot. The firefighting robot is integrated with an embedded system. The prototype system is designed to detect and extinguish fire. It aims to reduce air pollution caused due to fire. The robot is designed to detect fire in small floor plans. The task of extinguishing fire is divided into smaller tasks. Each task is carried out in most appropriate way. The robot navigates in every room step by step, finds the fire in a room, approaches fire from fixed distance and then extinguishes fire [6-10].

A firefighting robot which included a project that aims to promote technology innovation to achieve a reliable and efficient outcome. The movement of the robot is controlled by the sensors which are fixed on the mobile platform.is to provide security of home, laboratory, office, factory and buildings is important to human life. They also developed an intelligent multisensory based security system that contains a firefighting system in our daily life. It included the design of the fire detection system using sensors in the system, and program the fire detection and fighting procedure using sensor- based methods [11-15]. Automatic Fire Detection System Using Adaptive Fusion Algorithm for Fire Fighting Robot. Conceptual analysis of firefighting robots' control systems [16-20].

A review of literature on firefighting robots shows that researchers have focused on developing autonomous systems capable of detecting, navigating, and suppressing fires in hazardous environments. Initial research focused on robots that are remotely controlled, with limited sensory and water spray capabilities, primarily to minimize human exposure to toxic smoke and high temperatures. More recent studies emphasize the use of cutting-edge technology that enables robots to locate hotspots, spot victims, and adjust their operation in response to the dynamic conditions of the fire. A number of papers address wheel, track and aerial drone solutions which will improve deployment in a cluttered or collapsed facility. Other problems mentioned by scholars include the battery life, the problem of being able to navigate through dust and smoke, and the high cost of development. The literature overall indicates that the purpose of development of a firefighting robot is not to replace human firefighters but to be used as a force-multiplier to enhance safety, efficiency, and effectiveness of fire response operations, as well as to lay foundation for future innovations in collaborative human–robot firefighting teams. Robots are difficult to move effectively on the ground due to smoke, debris and collapse. Extensive firefighting missions are limited due to short battery life. High temperatures can cause failure of sensors, electronics and mechanical components. Limited adoption through development, deployment and maintenance costs. There is a need for specialized training to control and maintain these robots. The effectiveness is diminished when an area is inside a building or underground. Robots are not as adaptable as humans in an unknown fire situation. Breakdowns or poor performance may result from harsh conditions. Larger fleets are difficult to deploy in a variety of environments cost-effectively.

2. Proposed System

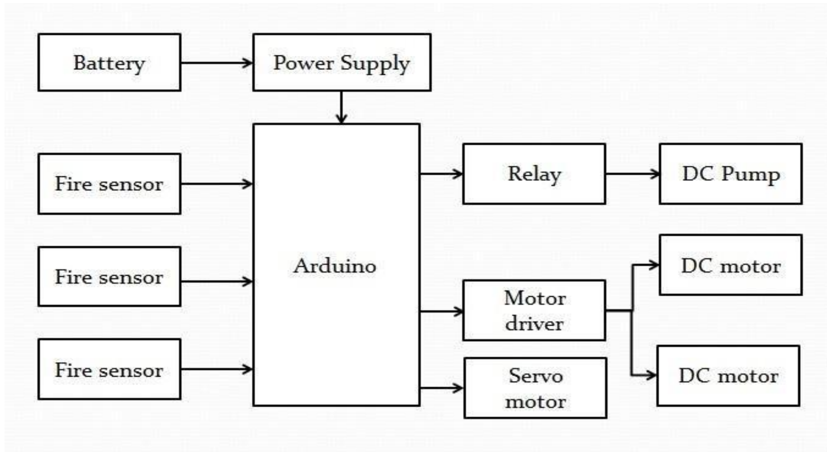

Fig. 1: Block diagram of project

This block diagram shown in figure 1 consists of different parts that are used to make this model and this is the place of alignments of the parts according to the connections. This block diagram we connected all the parts and made the prototype to make the working model to this is short and easy way to check all the parts which are available in the working model. The following requirements must be taken into account to design and implement a firefighting robot which monitors the part affected by the fire using IOT:

Sensors: The robot should have sensors to sense the presence of fire, smoke, and temperature, as well as other safety issues in the affected area. Accurate and reliable sensors are required, and the sensors should be able to send out data in real-time to the central control system.

Navigation System: The robot must be able to use a navigation system to traverse the terrain, avoid obstacles and find the fire source. The navigation system should be reliable, efficient and accurate, and be adaptable to different environments.

Communication system: Reliable communication system to pass data to the central control system. Communication system needs to be capable of real-time transmission of data and it is required to work in connectivity challenged environments.

Power supply: A reliable power supply system sufficient for an extended period of time must be used with the robot. The power supply system needs to be capable of enduring high temperatures and other dangers encountered during a fire incident.

Safety features: The robot should have safety features to prevent it from being damaged or destroyed in the event of an accident or hazard. The safety features should also ensure the protection of firefighters and other staff during a fire.

Integration with the central control system: The robot should be able to be integrated with the central control system to allow firefighters to monitor and control the robot remotely. The central control system should be user-friendly and offer real-time information on the robot's performance.

Durability and maintenance: The robot should be built to be durable and easy to maintain. In addition, it should be easily maintained and repaired in case of damage or malfunction.

The proposed system is a robot that can automatically detect and extinguish fires without human intervention, providing better safety and reducing the risk of human lives and property. It is particularly effective in hazardous areas such as industries, warehouses and residential areas where fire accidents can cause high damage. The robot is constructed from a microcontroller system, normally an Arduino Nano, which is the "mind" of the entire project which reads input, and regulates output. The robot continuously searches the environment for fire with flame and temperature sensors. Once a fire is detected, the sensors send a signal to the microcontroller, the microcontroller will analyze the data and decide the direction of the fire source. On the basis of this information, the robot uses the motor driver module and DC motors to move towards the fire. The robot's movement is fully autonomous, enabling it to move efficiently towards the fire position.

When the robot gets near the fire, it powers on a water pump system which is linked to a water tank. The water is held in a tank and pumped out through a nozzle that is used to put out the fire; the spray direction can be adjusted by a servo motor for better accuracy. Once the robot has put out the fire, it halts or resets and continues to look for additional fires in the environment. In summary, the proposed firefighting robot system is an effective, low cost and reliable fire detection and suppression solution. It reduces the risk of human involvement in hazardous situations and will enable prompt response to fires. The system is capable of being further improved with the addition of other technologies like IoT, cameras and artificial intelligence in the future to offer smarter and more efficient fire safety solutions.

The working principle of the voltage monitoring and tripping system in a fire fighting robot is based on continuously measuring the supply voltage of the battery to ensure safe and reliable operation of the robot. The voltage sensor circuit is usually made up of a voltage divider or voltage sensor module connected to the battery and delivers a reduced voltage signal to the microcontroller. The microcontroller constantly monitors the voltage at its analog inputs and ensures safe operation by comparing with preset thresholds.

If the battery voltage is in the normal range, the system can enable the robot to function normally, such as moving, detecting fire, and pumping water. When, however, a certain minimum voltage is reached, which is the indication of a low battery condition, the microcontroller triggers a trip action. This could include shutting down motors, stopping the water pump, and de-energizing other high power systems to avoid damage to the system and conserve energy. The system can also incorporate a warning device, such as an LED indicator or buzzer, to alert the operator to the low voltage situation. When the voltage is again within a safe range (after recharging or battery replacement), the system can be reset and operated normally again. Thus, the voltage monitoring and tripping system plays a crucial role in protecting the robot’s components, improving efficiency, and ensuring uninterrupted and safe performance during firefighting operations.

The functional block diagram of a firefighting robot shows a general representation of the overall operation of a robot system in terms of its input, processing and output components that are coordinated as a group. In this system, the input block is a series of sensors which are constantly observing the surrounding air for the presence of fire like flame sensors and temperature sensors. They are designed to identify heat or fire and then turn it into an electrical signal which is transmitted to the processing unit. The microcontroller (Arduino Nano) is at the heart of the processing block, serving as the robot's brain. It receives signals from the sensors, processes the data and takes decisions according to the instructions programmed. The microcontroller sets the direction of motion and appropriate movements to be taken to put out the fire depending on the input conditions.

Components in the output block include motor driver, DC motors, water pump, and servo motor. The motor driver controls the movement of the DC motors enabling the robot to move towards the fire source. When the robot comes to the fire, the microcontroller turns on the water pump and the servo motor assists in controlling the direction of the water pump to cover the fire the best. These are all powered by a battery supply, supplying the required energy for the entire system. The functional block diagram, therefore, illustrates conceptually the relationships between the input, processing, and output blocks to provide autonomous fire detection and suppression.

3. Hardware Design

The hardware design of the firefighting robot aims to select and integrate physical parts that have the ability to detect fire, control motion, and extinguish fire efficiently. It forms the backbone of the system, ensuring that all modules work together in a coordinated and reliable manner. All operations are controlled by a microcontroller like an Arduino Nano and depend on the information received from the sensors. The primary input devices to detect fire and heat level around the robot are the flame sensors and temperature sensors respectively. These sensors provide real-time data to the microcontroller, enabling quick and accurate decision-making. To move, a DC motor is used and a motor driver module is used to control the direction and speed of the robot. The motor driver is connected between microcontroller and motors to ensure smooth navigation towards fire source. A water pump system is included in the hardware design to be used to extinguish the fire, using a small water tank. When fire is detected, the pump is operated by the microcontroller with water being sprayed out of a nozzle. The motor can also be a Servo to control the direction of water flow for improved precision. Each one of the components is connected to a battery supply, which allows the robot to be portable and operate separately. Overall, the hardware design plays a crucial role in achieving an efficient, responsive, and autonomous firefighting system.

Arduino is an open-source platform used for building electronics projects. Arduino consists of both a physical programmable circuit board (often referred to as a microcontroller) and a piece of software, or IDE (Integrated Development Environment) that runs on your computer, used to write and upload computer code to the physical board. Arduino is a single-board microcontroller meant to make the application more accessible which are interactive objects and its surroundings. Arduino is an open-source electronics platform based on easy-to-use hardware and software. The hardware features with an open-source hardware board designed around an 8-bit Atmel AVR micro controller or a 32- bit Atmel ARM. The Arduino UNO is a popular microcontroller development board used for building electronics projects. It's based on the ATmega328P microcontroller, and it features an easy-to-use programming environment, making it ideal for both beginners and advanced users shown in fig 2.

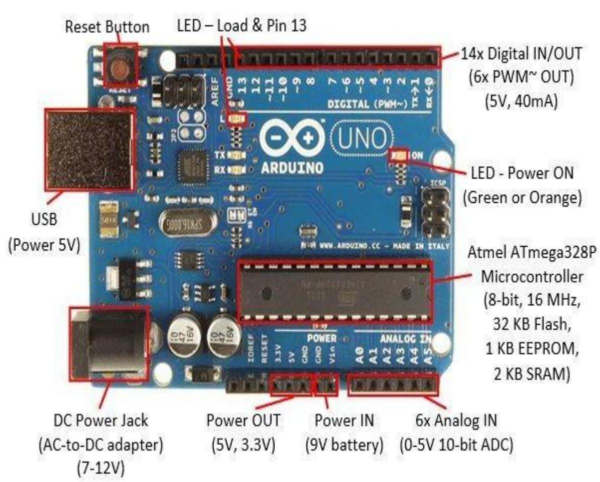

Fig:2: Arduino UNO

Fig. 3. Flame sensor

Fig 3 shows is a Flame sensor. Usually, in the infrared spectrum, all objects radiate some form of thermal radiation. These types of radiation are invisible to our eyes, and can be detected by an infrared sensor. The emitter is simply an IR LED (Light Emitting Diode) and the detector is simply an IR photodiode that is sensitive to IR light of the same wavelength as that emitted by the IR LED. When IR light falls on the photodiode, the resistances, and these output voltages, change in proportion to the magnitude of the IR light received.

4. Software Design

STEP-1: ARDUINO IDE

Once the software has been installed on your computer, go ahead and open it up. This is the Arduino IDE and is the place where all the programming will happen. Take some time to look around and get comfortable with it.

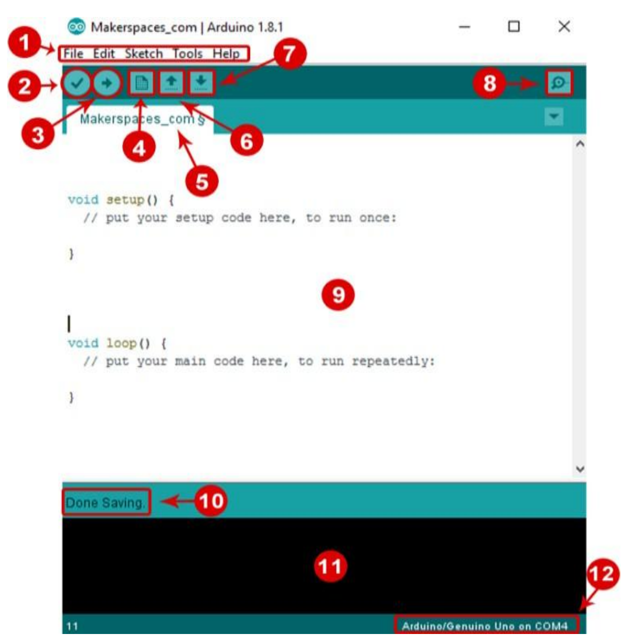

Fig: 4. Arduino tools

STEP-2: CONFIGURATION TOOLS

- Menu Bar: Gives you access to the tools needed for creating and saving Arduino sketches.
- Verify Button: Compiles your code and checks for errors in spelling or syntax.
- Upload Button: Sends the code to the board that's connected such as Arduino Uno in this case. Lights on the board will blink rapidly when uploading.
- New Sketch: Opens a new window containing a blank sketch.

- Sketch Name: When the sketch is saved, the name of the sketch is displayed here.
- Open Existing Sketch: Allows you to open a saved sketch or one from the stored examples.
- Save Sketch: This saves the sketch you currently have open.
- Serial Monitor: When the board is connected, this will display the serial information of your Arduino
- Code Area: This area is where you compose the code of the sketch that tells the board what to do.
- Message Area: This area tells you the status on saving, code compiling, errors and more.
- Text Console: Shows the details of an error messages, size of the program that was compiled and additional info.
- Board and Serial Port: Tells you what board is being used and what serial port it is connected to.

STEP 3: LINK ARDUINO UNO TO PC

- At this point you are ready to connect your Arduino to your computer. Plug one end of the USB cable to the Arduino Uno and then the other end of the USB to your computer's USB port.
- Once the board is connected, you will need to go to Tools then Board then finally select Arduino Uno
- Next, you must tell the Arduino which port you are using on your computer.
- To select the port, go to Tools then Port then selects the port that says
- Arduino

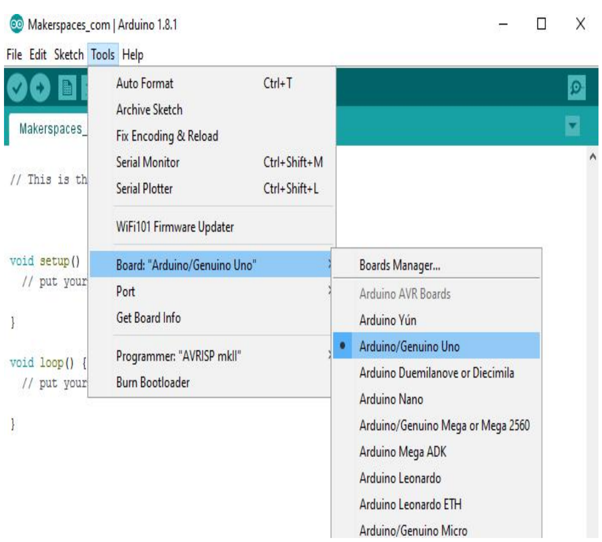

Fig:5. Board linking tool

STEP 4: COMPILE AND UPLOAD

You need to click on the verify button (check mark) that is in the top left of the IDE box. This will compile the sketch and look for errors. Once it says "Done Compiling" you are ready to upload it. Click the upload button (forward arrow) to send the program to the Arduino board.

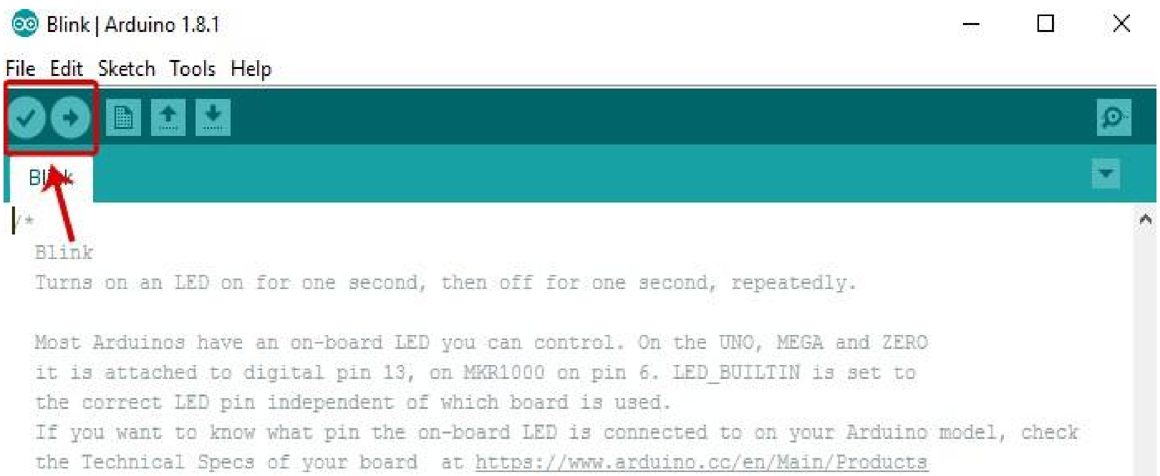

Fig:6. Code verification & upload

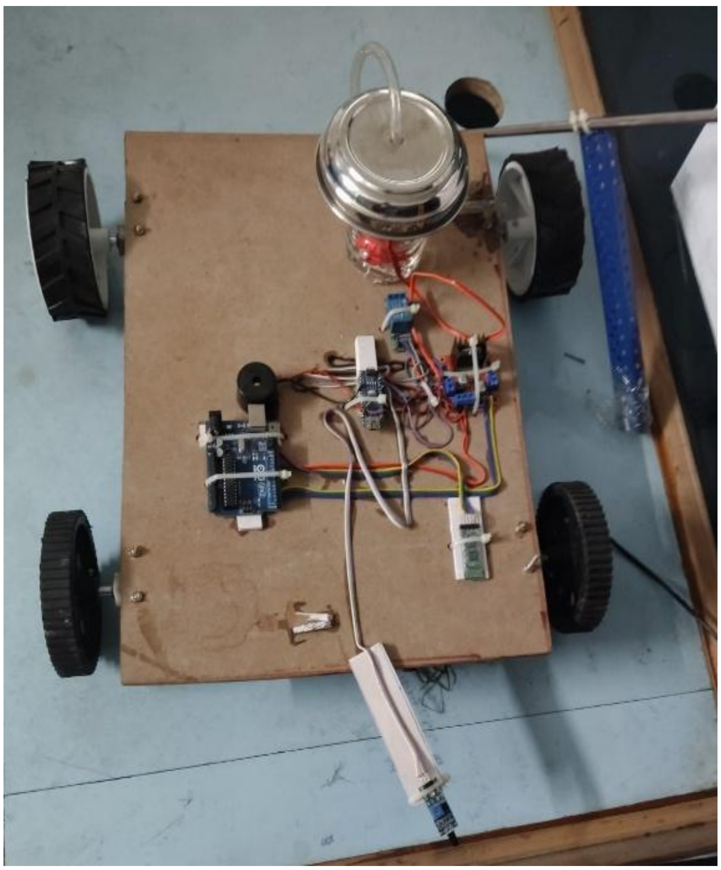

Fig: 7. Working Model of Proposed Method

5. Results and Discussion

The results of the implementation showed that the robot was able to detect fires using temperature and smoke sensors and spray water to extinguish the flames. Further, the robot could have tracked temperature, humidity, and gas levels in the area for changes and provided real-time data that can be used to enhance the firefighting process. The results also showed that the robot was able to navigate through different types of terrain and obstacles to reach the affected area. The robot moved smoothly as the motor drivers and motors were used to move the robot around, and they did not collide with any objects.

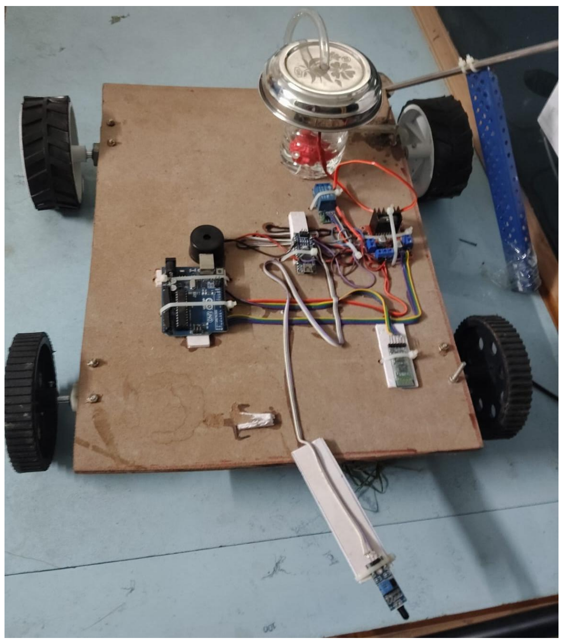

Fig. 8: Power Supply of the Project

However, one of the challenges encountered during the implementation was ensuring the reliability of the sensors in detecting fires and environmental changes. It was important the sensitivity of the sensors be adjusted to avoid nuisance alarms yet detect fires promptly and accurately. Lastly, the IOT-based firefighting and affected area monitoring robot offers integrated and efficient monitoring and fighting solution. The real-time data collected by the robot can be used to improve firefighting techniques and prevent future fires. With further research and development, this technology has the potential to revolutionize firefighting and disaster response. Response time analysis of a firefighting robot is one of the key performance metrics to determine the speed at which the robot responds to fire and initiates necessary actions to suppress it. It is the sum of the time beginning from the detection of the fire by the sensors until the extinguishing mechanism is activated, for example the water pump. A faster response time shows a more efficient and reliable system which is vital in minimizing the damage from fire and for safety. There are several factors that affect response time, such as the sensitivity and location of the flame sensors, the speed of the microcontroller to process the signal and the speed at which the robot is moving. First, when the flame sensor detects fire, it sends a signal to the microcontroller, the microcontroller processes the signal and outputs control signals to the motors. The robot then is driven towards the fire source and when it has reached a fire-fighting distance, the water pump is turned on to put out the fire. It takes a total time to react, which is the sum of detection time, decision-making time, movement time and action time. The response time is analyzed by doing multiple experiments, varying the distance and direction of the robot from the fire source. Timers or observation are used to gauge the duration of each stage and results are recorded and compared. The response time can be increased due to any delay in detection, slow movement or inefficient control logic. By analysing these factors, improvements can be made in sensor accuracy, programming efficiency, and motor performance to achieve a faster and more effective firefighting robot system.

Conclusion

The Proposed approach of modular design strategy was a good solution in implementing the firefighting robot to help people at the critical condition. The proposed robot can move in forward, backward, left, right and can stop also. It reduces human efforts and protects their property. Robot detects fire and extinguishes the fire with the help of a sprinkler pump. A firefighting and affected area monitoring robot is proposed based on the Internet of Things environment, which can take instant steps during fire accidents. This robot can be used to reduce the risk of human firefighters in area which is out of reach for human beings. Industries with a higher risk of fire accidents can use this robot to avoid huge damage. In the future re, Machine Learning and AI systems can be implemented to improve the performance of the robot.

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