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Artificial Intelligence-Driven Autonomous Firefighting Robot using Arduino and Bluetooth

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Abstract
This research presents the design and development of an Artificial Intelligence (AI)-driven autonomous firefighting robot using Arduino and Bluetooth technologies. The robot is equipped with three infrared flame sensors, an MQ-2 gas sensor, and a water pump, enabling it to detect and extinguish fires independently. The AI algorithm, implemented on the Arduino microcontroller, allows the robot to navigate through a fire scene, identify the fire source, and deploy extinguishing agents. The robot's sensor array detects flames in multiple directions (forward, left, and right) and gas leaks, triggering alerts and autonomous response. Bluetooth communication allows for remote monitoring and control, ensuring safe and efficient operation. Experimental results demonstrate the robot's effectiveness in detecting and extinguishing fires rapidly and effectively, showcasing its potential for enhancing fire safety in various environments. This low-cost prototype combines sensor-based autonomy with wireless remote control/monitoring, offering a promising solution for reducing fire-related risks and promoting smart fire safety applications.

Keywords: Bluetooth Module, Arduino, Firefighting Robot, Artificial Intelligence (AI), Infrared Sensors, Fire Detection.

I. INTRODUCTION
Fire incident is a disaster that can potentially cause loss of life, damage to property and injury to the affected victim. Fire fighters are primarily tasked to handle fire incidents, but they are often exposed to higher risks when extinguishing fire [17], especially in hazardous environments such as in nuclear power plant, petroleum refineries and gas tanks [18, 19]. They are also faced with other difficulties, particularly if fire occurs in narrow and restricted places. Unpredictably, fires can spread quickly, consuming entire buildings in a matter of seconds. Prompt actions are essential in these kinds of emergency scenarios. Conventional firefighting techniques frequently depend on human intervention and results in untimely response and difficulties. Thus, a robot can be employed to address these problems. Robots are designed to remove human factor from labour intensive or dangerous work and also to act in inaccessible environment. With the invention of such a devices, lives and properties can be saved. A recent trend that has become popular is to use robots instead of humans to handle fire hazards. This is mainly because they can be used in situations that are too dangerous for any individual to

involve themselves in. There are several existing types of robots for firefighting at home. Autonomous indoor firefighting robot are designed to detect for indoor fires, navigate to a suitable proximity of the fire and extinguish it. The robot processes information from its sensor and hardware components. Ultraviolet, infrared and visible light are used to detect the components of the environment. The main and only work is to deploy the robot in a fire prone area and the robot will automatically work once it detects a fire breakout.

II. LITERATURE REVIEW

Many authors have proposed different techniques for firefighting. Cutting-edge sensors and algorithms are employed by intelligent fire recognition systems for rapid and precise detection of fires [1]. A fire incident at the industry poses a serious risk to human life and would result in significant losses. Early fire detection and modest firefighting efforts could prevent significant losses and save lives. To carry out early firefighting action, the paper [2] suggested integrating the autonomous firefighting mobile robot into Internet of Things (IoT) system. In the event that a fire is discovered, the IoT system notifies the fire safety division and launches a mobile robot into action. Using a path-planning algorithm, a firefighting robot arrives at a fire location, engages in firefighting operations, and transmits the video feed of the fire location to the control room [3]. In addition to alerting the fire safety officers, early action prevents the fire from spreading. By watching the video that the firefighting robot sent, fire safety officers can better prepare for handling the fire incident in the interim. In [4] a small crawler robot was designed using the virtual prototype technology, taking into account the unique working environments and safety of firefighters in homes and other fire scenes. The firefighting robot's general design scheme was suggested, and a stand-alone suspension system with effective shock absorption was created. The development of an explosion-proof waterproof shell for a specialized robot allows for precise temperature and unsafe object detection at the fire scene through the robot's vision and temperature identification [5,6]. Research shows that the small crawler fire-fighting robot has high detection intelligence and structural reliability, which is of great significance to the fire-fighting operations [1]. Businesses with a high risk of fire incidents could combine their current fire alerting system with a mobile robot that fights fires [3]. A robotic system called the Arduino-based Fire Fighting Robot with SMS Alert System is made specifically to detect and put out indoor fires. The robot looks for signs of fire using flame sensors. When a fire is detected, the user can receive alerts via SMS messages from the robot thanks to its GSM module. This makes it possible to respond quickly in order to reduce damage and save lives. The robot is made up of an Arduino board, sensors, motor drivers, and a GSM module. With the extra advantage of remote communication and control, the Arduino-based Fire Fighting Robot with SMS Alert offers a dependable and effective solution for fire detection and suppression overall [7,8]. Elsewhere, another project used Arduino technology to create an autonomous firefighting robot that could locate and put out fires [9]. Humanoid robot applications [20, 21] are the subject of active research in an attempt to increase productivity, security, efficacy, and quality of work while lowering the number of firefighter fatalities and injuries [10]. The robot can improve the fire's quality, productivity, safety, and efficiency. It is smaller and more pliable than other robots. Furthermore, the robot's small size and automatic control make it suitable for use in hazardous environments like tunnels [22] or nuclear power plants where fires occur in tight spaces. This developed autonomous system shows off its ability to automatically locate fires and put them out with water that has been stored in a container on it [11]. The development of an autonomous, human-free firefighting robot that can identify and put out fires is the main topic of this report. It is crucial that we have a system in place to handle a dangerous incident like this because fires can break out in our homes, workplaces, factories, or labs at any time. The systems that are currently on the market are smoke detectors, which are effective but have certain drawbacks. For example, they cannot detect small fires and the water showers do not provide enough coverage to completely put out a fire. Additionally, the smoke detectors fail to alert people to the location or status of the fire, which can cause long-term harm because it delays help. Other related works focused on using ultrasonic sensors [12,13], light detection and ranging (LiDAR), and infrared sensors to help robots navigate through complex and dynamic environments. With the aid of light-dependent resistors (LDRs), a line-follower robot [14] can track and navigate through a maze of lines, avoiding obstacles [23-25], and put out any indoor fires. This paper focuses on the design and construction of a mechatronic system for indoor firefighting. The objective was to create a machine that could identify and extinguish small fires in closed spaces. With the help of infrared flame sensors, the robot detects the fires and autonomously navigates to the fire location and safely sprays it with water. In order to facilitate the work of firefighters and minimize the number of casualties, we develop an automated system for the early detection and extinguishment of fires. Simulation results in proteus and practical experiments were conducted to verify the effectiveness of proposed robotic system. The experiment results showed that the robot was able to detect fires in three different directions, viz., forward, left, and right directions; and was able to rapidly put off the fires, effectively [15].

III. MATERIALS/METHOD

3.1. Materials used in this research are listed in the table below

S/N	Name of components	Number of used
1	Arduino	1
2	Infrared Sensors	3
3	Water Tank	1
4	MQ-2 Gas Sensor	1
5	Voltage Regulators	1
6	DC Motors	2
7	Resistors	4
8	Batteries	3
9	Switch	1
10	Ultrasonic Sensor	1
11	Servo motor	1
12	DC Pump motor	1
13	LEDs	3
14	Relay	1

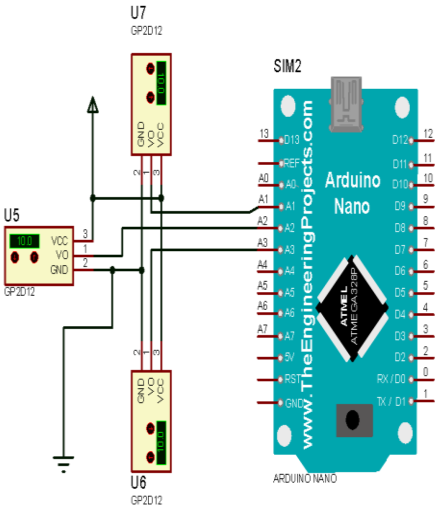


Figure 3.1: The interfacing of the three infrared sensors IR (left, right and front) to the Arduino Nano

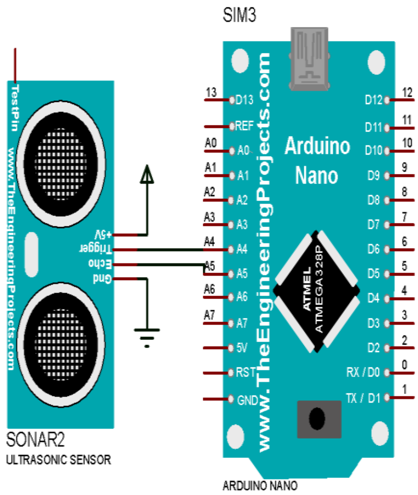


Figure 3.2: The interfacing of the ultrasonic sensor to the Arduino Nano

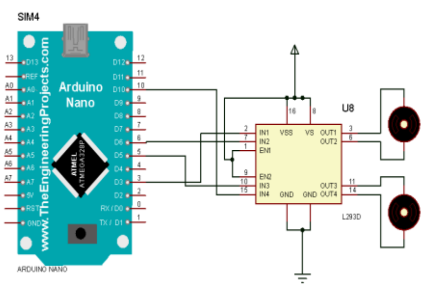


Figure 3.3: The interfacing of the Arduino to the DC motor

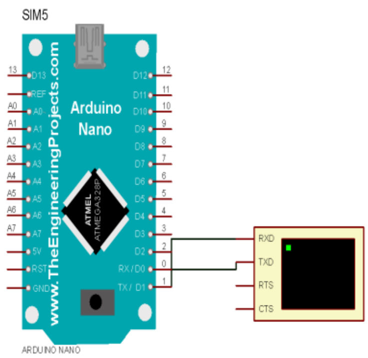
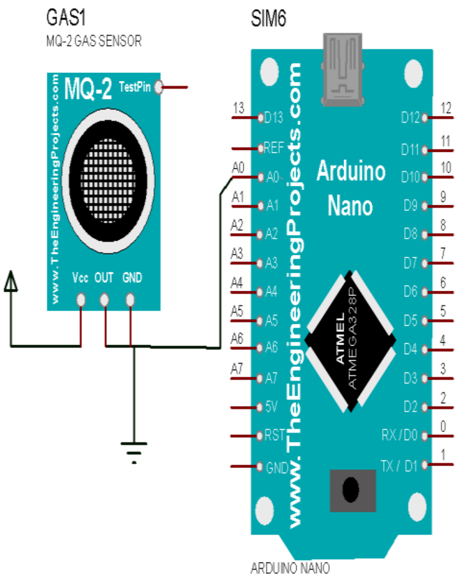


Figure 3.4: The interfacing of the Arduino to the Bluetooth Module



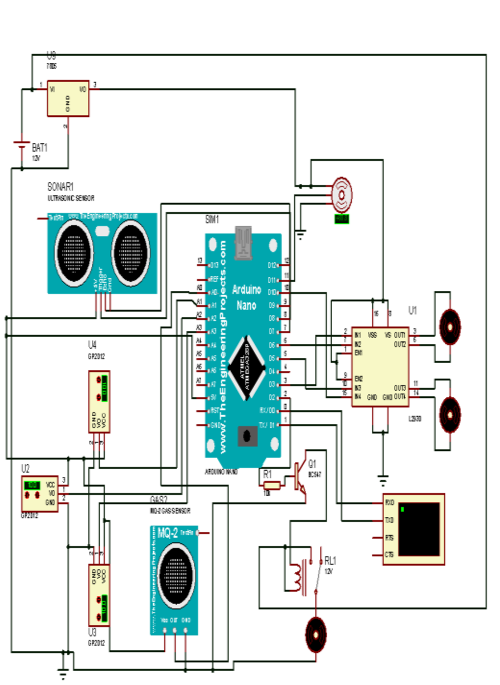


Figure 3.5: The interfacing of the Arduino to the MQ-2 sensor

Figure 3.6: Interfacing of the whole system

3.2. Method

The system uses dry cell batteries for its power. You can charge the batteries with the help of the adapter so it does not run low or out of charge always. When you power on the system with the help of the switch button, the robot will start moving. If it detects an obstacle with the help of the ultrasonic sensor used in the research, it will change direction. The robot will continue moving until it senses fire in the environment; it senses the fire with the help of the left, right, and front infrared sensors mounted on the robot. Immediately it senses the fire, it will move the water sprinkler [26] in the direction of the fire and pour water on it with the help of the water from the tank mounted on the robot. A Bluetooth module is used in the research to indicate the direction where the fire is, either left, right, or front. In this research we also used the MQ-2 sensor to sense the presence of gas leakage; if there is gas leakage, it will also send a message using the Bluetooth module and also sound an alarm with the help of a buzzer.

IV. RESULTS

The program was written in the Arduino integrated development environment (IDE) and compiled into machine code (binary file). With the help of the IDE's upload functionality, this machine was flashed into the Arduino board's ATMega328P microcontroller. The Arduino Uno controller on the robot's chassis is responsible for both the robot's navigation in the direction of the fire and its fire detection and fire extinguishing ability. The water pump on board the robotic vehicle is servo-controlled. With the help of the dual H-bridge module used to drive the robot's two rear motors, two motors are interfaced to the microcontroller to move the vehicle, and a front wheel is used to position the robot. The robot body is equipped with a water tank and water pump, which are controlled by the microcontroller output. The microcontroller is interfaced with a motor driver integrated circuit (IC), which allows the controller to drive the motors. On the robot chassis, three infrared flame sensors are fixed to detect fire and travel to the site to extinguish the fire. Also, the MQ-2 sensor is used to detect the presence of gas leakage. The smartphone is connected to the Bluetooth module in order to display the status of the robot if it detects either fire or gas leakage.

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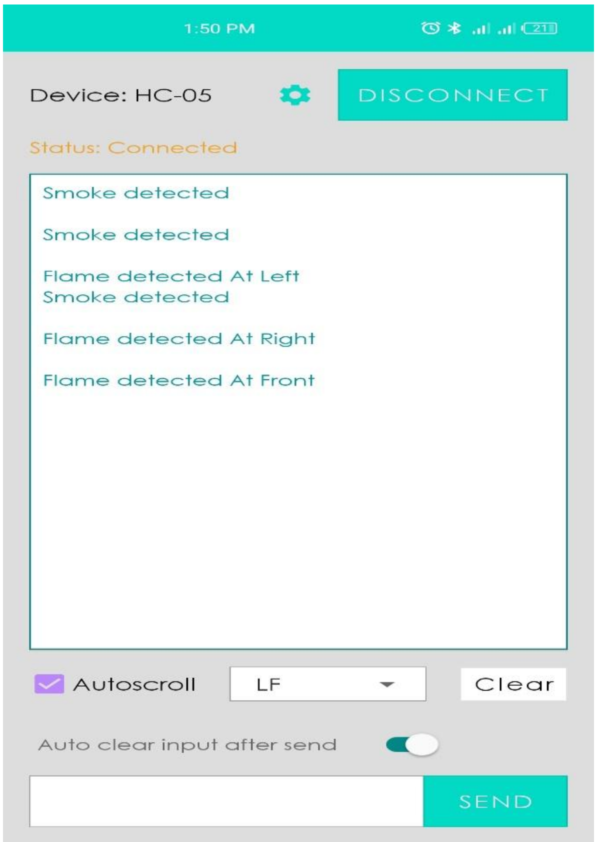

Figure 4.1: Result obtained or displayed from the Bluetooth module

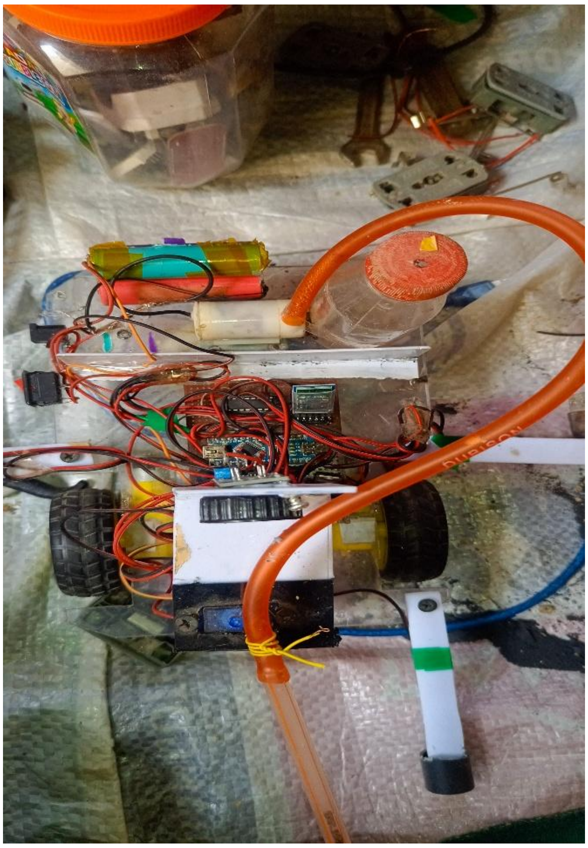

Figure 4.2: Construction of the firefighting robot

CONCLUSION

In this study, a robotic system was designed and built, and its functionality was verified in a simulated environment as well as in real-world trials. The results of the study show that the robot is capable of accurately and swiftly detecting fire and gas. By creating a robotic system that could detect small flames in restricted locations, identify the fire's source independently, and extinguish it, the objective was achieved [28-41].

Future Directions

Future directions for low-cost autonomous firefighting robots include enhancing navigation and detection with advanced sensors, improving water delivery with more precise aiming, and integrating advanced communication for remote operation and data analysis. Other key areas are adding obstacle avoidance, multi-sensor fusion (e.g., adding gas sensors), and improving the power supply and chassis design for greater durability and maneuverability.

Enhanced sensing and navigation

i. **Advanced sensors:**
Integrate more sophisticated sensors like thermal cameras for heat detection, gas sensors for identifying specific hazards, and ultrasonic sensors for better obstacle detection and mapping.

ii. **Multi-sensor fusion**:
Combine data from multiple sensors to improve accuracy and reliability. This can help the robot better identify the fire source, even in cluttered or smoky environments.

Improved fire suppression

i. **Targeted water delivery:**
Use a servo motor to adjust the nozzle's position, allowing for more precise aim and more effective extinguishing, especially against small fires.

ii. **Variable water pressure**:
Implement a system to control the water pump's output, allowing for adjustable water pressure based on the fire's intensity.

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Advanced control and communication

i. **Improved Bluetooth integration:**
Move beyond basic manual control to use Bluetooth for real-time data streaming, such as video from an integrated camera, and to receive more complex commands.

ii. **Long-range communication**:
Explore alternatives like Wi-Fi, LoRa, or even integrating a GSM module for sending alerts to a wider network or controlling the robot from a greater distance.

iii. **AI and machine learning**:
Use machine learning for more sophisticated fire detection, path planning, and to help the robot learn from its environment to improve its performance over time.

Physical design and power [42-44].s

i. **More robust chassis:**
Build a more durable chassis that can better withstand heat and physical impact from debris.

ii. **Improved power management:**
Develop more efficient and longer-lasting battery solutions and consider integrating a hybrid power system for extended operation.

Safety and data analysis

i. **Data logging and analysis:**
Log sensor data and operational performance to help identify areas for improvement and to provide valuable data for post-incident analysis.

ii. **Emergency alerts:**
Add an alert system, such as SMS alerts, to notify humans immediately of a detected fire, even if the robot is the first responder [27].

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