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Design, Analysis and Fabrication of Solar Powered Automatic Fire Fighting Robot

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Abstract - This paper presents the design, analysis, and development of a solar-powered automatic fire-fighting robot aimed at reducing human involvement in hazardous fire situations. Fire accidents pose serious risks to life and property, especially in environments that are difficult to access. The proposed system integrates renewable energy with embedded systems to provide an efficient and eco-friendly solution. The robot is powered using a 5W solar panel and a 12V battery, ensuring continuous and sustainable operation. An Arduino Nano serves as the main control unit, processing inputs from flame sensors and an ultrasonic sensor for fire detection and obstacle avoidance. Upon detecting fire, the robot autonomously navigates toward the source and activates a water pump controlled via a relay module to extinguish it. A servo motor is used to direct the water flow accurately. The system demonstrates reliable performance in detecting and suppressing smallscale fires under controlled conditions. The results indicate that the proposed robot is cost-effective, energy-efficient, and suitable for applications in residential, laboratory, and small industrial environments. This work highlights the potential of combining solar energy with robotics for intelligent fire safety systems.

Keywords: Solar Energy, Fire-Fighting Robot, Arduino Nano, Autonomous System, Flame Detection, Robotics

I. INTRODUCTION

Fire is one of the most dangerous and destructive hazards, causing significant loss of life, property, and environmental damage. In industrial, residential, and commercial environments, fire accidents can spread rapidly due to flammable materials, electrical faults, and human negligence. Conventional firefighting methods require direct human involvement, which exposes firefighters to high temperatures, toxic gases, and life-threatening conditions. Therefore, there is a growing need for intelligent and automated systems that can reduce human risk and improve fire response efficiency. Recent advancements in robotics and embedded systems have led to the development of autonomous fire-fighting robots capable of detecting and extinguishing fire without human intervention. Many existing systems use microcontrollers, flame sensors, and water-based suppression mechanisms. However, most of these systems rely on conventional power sources, limiting their sustainability and operational time.

To address these limitations, this paper presents the design and development of a solar-powered automatic firefighting robot. The proposed system integrates an Arduino Nano microcontroller with flame sensors for fire detection and an ultrasonic sensor for obstacle avoidance. A solar energy system consisting of a solar panel, charge controller, and battery ensures continuous and eco-friendly operation. The robot autonomously detects fire, navigates toward it, and activates a water pump to extinguish it.This work aims to provide a cost-effective, energy-efficient, and reliable solution for small-scale fire safety applications such as homes, laboratories, and industrial environments.

II.METHODOLOGY

The methodology adopted for the development of the solar-powered automatic fire-fighting robot involves systematic stages including requirement analysis, system design, component selection, fabrication, and testing. The proposed system integrates solar energy with embedded control and robotic mechanisms to achieve autonomous fire detection and suppression.

A. Requirement Analysis

The system is designed to perform key functions such as autonomous fire detection, obstacle avoidance, and fire suppression. Additionally, it ensures energy efficiency by utilizing solar power for continuous operation.

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B. System Design

The overall system consists of three major subsystems: mechanical, electrical, and control. A four-wheel drive chassis powered by Johnson motors provides mobility. The control system is based on an Arduino Nano, which processes inputs from sensors and controls actuators accordingly.

C. Sensor Integration

Three digital flame sensors are used to detect the presence and direction of fire. An ultrasonic sensor is incorporated for obstacle detection and navigation, ensuring safe movement of the robot in different environments.

D. Fire Suppression Mechanism

A 12V water pump is used to extinguish fire and is controlled through a relay module. An SG90 servo motor is employed to adjust the direction of the nozzle, enabling accurate targeting of the flame.

E. Power System

The robot is powered using a 5W solar panel connected to a solar charge controller and a 12V battery. This setup ensures sustainable and uninterrupted operation, especially in remote areas

III.MODELING AND ANALYSIS

The modeling and analysis of the solar-powered automatic fire-fighting robot involves the design of mechanical structure, electrical system, and component integration. The system is developed by combining sensors, control unit, and power system to achieve autonomous fire detection and suppression.

A. System Model

The system consists of an Arduino Nano as the main controller, which receives input from flame sensors and an ultrasonic sensor. Based on the input, the controller drives the motor driver for movement and activates the water pump through a relay module. The entire system is powered by a solar panel and battery setup.

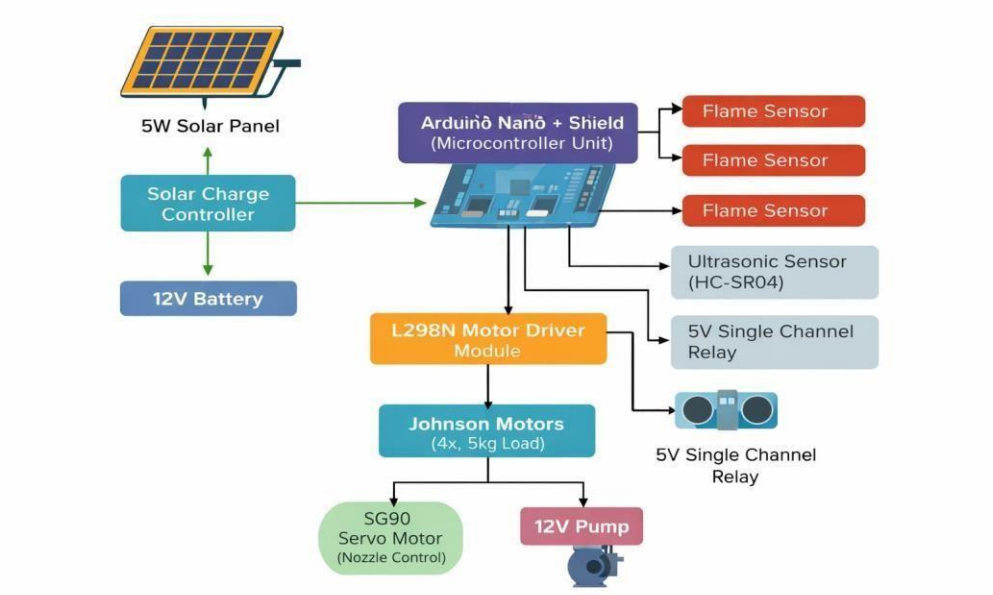

Figure 1: Block Diagram

B. Mechanical Model

The mechanical structure of the robot is fabricated using wooden planks, which provide sufficient strength, low cost, and ease of fabrication. The use of wood makes the system economical and suitable for prototype development. The chassis is designed to support all components including motors, battery, pump, and control unit while maintaining stability during operation. A four-wheel drive (4WD) system powered by Johnson motors is implemented to ensure smooth and efficient movement in all directions. The

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wheels are mounted securely on the wooden base, allowing the robot to navigate different surfaces. The overall design ensures proper weight distribution, stability, and ease of assembly.

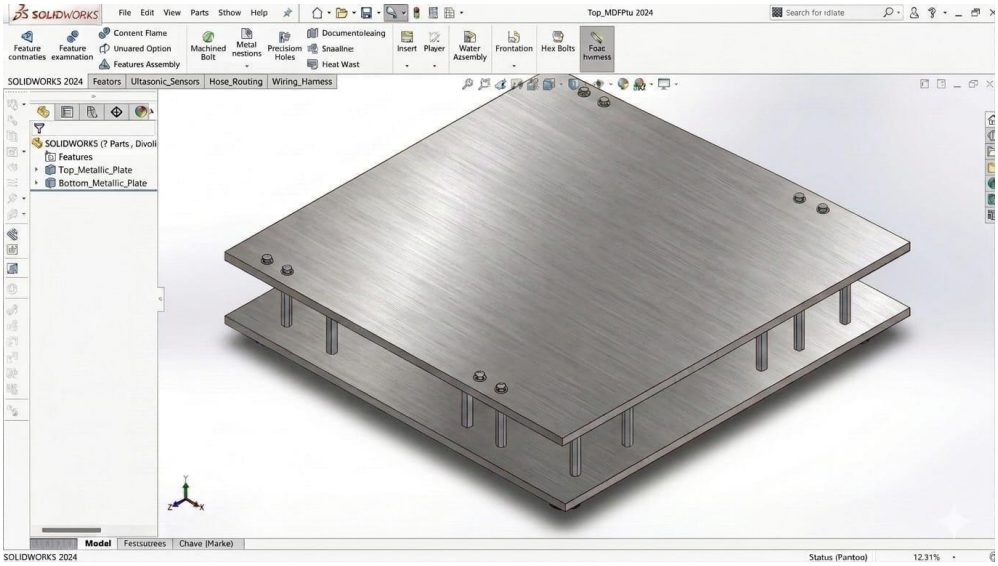

Figure 2: 3D CAD Model

C. Material and Components

The proposed system is developed using readily available and cost-effective components. The selection of materials and components is based on performance, efficiency, and affordability. The mechanical structure is fabricated using wooden planks, while the electronic system integrates sensors, actuators, and control units for autonomous operation. The details of the components used are presented in Table 1

Table 1: Components And Specifications

Components	Specification	Function
Flame Sensor (Digital)	Fire/flame detection	3.3–5V, 60° detection angle, digital output
Ultrasonic (HC-SR04)	Distance measurement	2–400 cm, 40 kHz
Arduino Nano + Shield	Main microcontroller	ATmega328P, 14 I/O, 6 Analog, 5V
L298N Driver	Motor controller	Dual H-Bridge, 5–35V
Johnson Motors	Drive system	12V DC, High Torque (5kg load)
SG90 Servo Motor	Nozzle Direction Control	5V, 180 degree rotation
Water Pump	Fire extinguisher	12V DC, 120L/htr
Solar Panel	Renewable power Source	5W, 12V
Battery	Backup power Supply	12V, 7Ah
Relay Module (5V, Single Channel)	Pump Switching Control	5V input, 10A switching
Solar Charge Controller	Battery Charging Regulation	12V Sysyem Compatible
Wooden plank	Base Structure	Support

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D. Analysis of System

The system was analyzed based on performance parameters such as fire detection accuracy, response time, and power efficiency. The flame sensors provided quick detection, while the ultrasonic sensor ensured obstacle avoidance. The solar power system improved sustainability and reduced dependency on external power sources. The robot demonstrated effective fire suppression in small-scale environments.

IV. RESULTS AND DISCUSSION

The developed solar-powered automatic fire-fighting robot was tested under controlled conditions to evaluate its performance in terms of fire detection, navigation, and extinguishing capability. The system successfully demonstrated autonomous operation by detecting fire using flame sensors and moving toward the source. The ultrasonic sensor effectively avoided obstacles during navigation.

The water pump mechanism was activated through a relay module and was able to extinguish small-scale fires efficiently. The servo motor provided accurate control of the water nozzle, improving targeting performance. Additionally, the solar power system ensured continuous operation by charging the battery, making the system energy-efficient and sustainable.

However, slight variations in flame detection were observed under high ambient light conditions. The navigation system showed minor deviations when obstacles were irregularly placed. Overall, the system performed reliably and is suitable for small-scale applications such as laboratories, residential areas, and workshops.

S.N	**Paramerters**	**Observation**
1	Fire Detection	Fast And Accurate
2	Response Time	Quick Response
3	Navigation	Smooth With minor deviation
4	Obstacle Avoidance	Effective
5	Fire Extinguishing	Efficient For Small Fires
6	Power System	Stable solar charging
7	Overall Performance	Relieable

Table2: Performance Analysis Of Robot

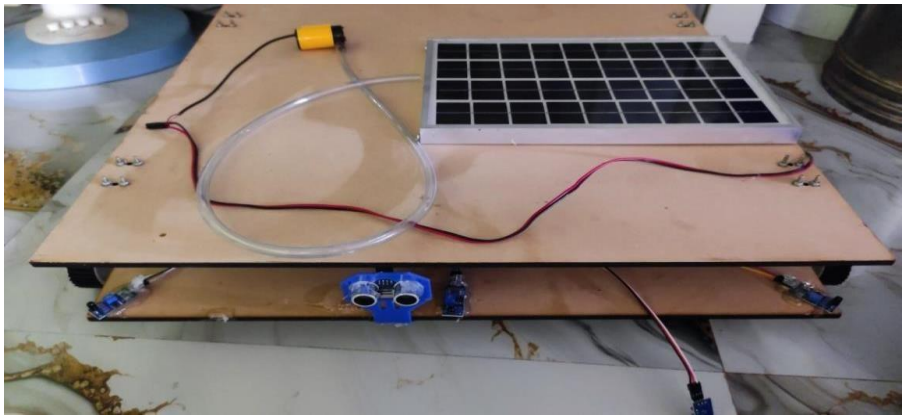

Figure3: Prototype of Fire Fighting Robot

V. CONCLUSION

The present work successfully demonstrates the design and development of a solar-powered automatic fire-fighting robot capable of detecting and extinguishing fire without human intervention. The system integrates flame sensors, an ultrasonic sensor, and an Arduino Nano to achieve autonomous operation and efficient navigation. The fire suppression mechanism using a water pump and

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servo-controlled nozzle proved effective in handling small-scale fire incidents.The incorporation of a solar energy system enhances the sustainability of the robot by reducing dependency on conventional power sources and enabling continuous operation. The use of low-cost and easily available components makes the system economical and suitable for practical applications. Although the system performs reliably under controlled conditions, certain limitations such as sensitivity to environmental light and basic navigation logic were observed. These limitations indicate the scope for further improvement. Overall, the developed robot provides a safe, cost-effective, and energy-efficient solution for fire detection and suppression, and it can be effectively utilized in residential, laboratory, and small industrial environments.

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