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Development of Smart Solar Robot for Advanced Surveillance Systems

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Abstract: The rapid evolution of defence and security technologies has intensified the demand for intelligent, energy-efficient robotic systems capable of executing surveillance, monitoring, and controlled response operations in hazardous environments without exposing personnel to direct risk. The present work involves the design, development, and fabrication of a smart solar-powered robotic platform specifically intended for defence support applications, combining renewable energy utilization, embedded control systems, and wireless communication to achieve sustained, reliable field operation. By harnessing solar energy as its primary power source, the system ensures extended deployment in remote and outdoor regio wr regions where conventional power infra- aststructure is limited, thereby enhancing endurance w while promoting sustainability.

Key words: Solar energy, Smart robo, national-na security.

1.0 Introduction: In modern warfare and border security, the need for advanced technology to enhance surveillance, reduce human risk, and improve operational efficiency has become increasingly important. A Smart Solar Robo for Defence Application is an innovative robotic system designed to assist military forces in performing critical tasks such as monitoring, reconnaissance, and threat detection in remote or hazardous environments. This robot is powered by solar energy, making it highly sustainable and suitable for long-duration missions without frequent battery replacement or recharging. By utilizing renewable energy, it reduces dependency on conventional power sources and ensures continuous operation even in isolated areas. The system is equipped with smart technologies such as sensors, cameras, and wireless communication modules, enabling real-time data transmission and remote control. It can detect obstacles, identify unusual movements, and capture live video footage, helping defense personnel make quick and informed decisions. Additionally, the robotic platform minimizes the risk to human soldiers by operating in dangerous zones such as border areas, minefields, and conflict regions. Its compact design, energy efficiency, and intelligent functionality make it a valuable asset in modern defense strategies.

Overall, the Smart Solar Robo represents a fusion of robotics, renewable energy, and defense technology, aiming to enhance national security while promoting sustainable innovation.Suryawanshi A.M.Gandhi R.S et al [1] Developed a robot capable of detecting metals, harmful gases, temperature, and humidity in its surroundings. It uses various sensors and a GSM module to send real-time alerts and data to the control room or user's mobile phone. The robot can move automatically, avoid obstacles, and perform surveillance tasks in areas unsafe for humans. The main goal of this system is to reduce human risk, improve monitoring accuracy, and provide a cost effective solution for defense and industrial applications. This intelligent robot plays an important role in enhancing security, disaster management, and remote area observation.S.Nallathambi et al [2] Fabricated robot vehicle which is controlled by Android application. This robot can move to any place and perform smartly within specified Wi-Fi range. The developed robot works on radio frequency technology. Android application sends the signal to radio frequency receiver which is mounted on robot by using Wi-Fi connection. The robot consists of night vision wireless camera which can transmit images or videos.

2.0 Methodology: The proposed system is an autonomous robotic platform powered by solar energy, designed for surveillance and reconnaissance in defence environments. It integrates renewable energy harvesting, embedded control systems, sensor fusion, and wireless communication to perform real-time monitoring in remote or hostile areas.

2.1.System Architecture: System architecture is the conceptual model and blueprint that defines the structure, behavior, and interaction of a system's components (software, hardware, and networks). It serves as a, fundamental design that ensures all parts work together to satisfy requirements, guiding development, maintenance, and scalability.

2.1.1 Power Generation and Management Module: A Power Generation Module in a Smart Solar Robot is an integrated system designed to harvest solar energy and convert it into usable electrical energy to drive robotic actuators, sensors, and computing components. It acts as an autonomous, eco-friendly energy source that eliminates the need for manual charging.

- Solar panels convert sunlight into electrical energy based on the principle of Photovoltaic Effect.
- A charge controller regulates voltage and prevents overcharging.
- Rechargeable batteries store excess energy for night or low-light operation.
- Power distribution ensures stable supply to all subsystems.

2.1.2 Control Unit: The control unit of a smart solar robot is the centralized microcontroller-based "brain" that manages all hardware components, processes sensor data, and executes autonomous or remote-controlled commands to maintain solar panel efficiency or perform field tasks. It bridges energy harvesting with actionable robotic movements

- A microcontroller (e.g., Arduino Uno or Raspberry Pi 4) acts as the brain of the robot.
- Responsible for:
  - Sensor data acquisition
  - Decision-making algorithms
  - Motor control
  - Communication handling

2.1.3 Sensing and Detection Module: The Sensing and Detection Module in a smart solar robot is an integrated subsystem responsible for gathering real-time data from the physical environment and the robot's internal state, converting these physical parameters into electrical signals for the main controller (e.g., Arduino, Raspberry Pi) to enable autonomous decision-making. It serves as the "eyes and ears" of the robot, enabling navigation, obstacle avoidance, solar efficiency optimization. The smart robot integrated with camera for recording of movements.

2.1.2.1.4 Mobility and Actuation Module:

A Mobility and Actuation Module in a smart solar rob robot refers to the integrated mechanical and ele-electrical subsystem responsible for the robot's mo movement, positioning, and task execution, poppowered entirely or partially by photovoltaic eneenergy.It converts solar electricity into kinetic eneenergy to enable autonomous navigation and pre-precise manipulation, often using DC motors, act actuators and intelligent control algorithms to fun to function in remote or off-grid

- DC motors with motor drivers enable movement.
- Chassis designed for rough terrain (tracked or wheeled).
- Navigation strategies:
  - Line-following (basic)
  - Autonomous path planning using sensor feedback

2.1.5 Communication Module: A communication module in a smart solar robot is an integrated electronic component that enables the robot to exchange data wirelessly with external systems, such as a user's smartphone, a base station, or a central cloud server. It serves as the vital link between the robot's onboard microcontroller (which processes sensor data) and the user, allowing for real-time monitoring of solar panel health, battery power, and cleaning status

- Wireless communication via:
  - RF modules / Wi-Fi / GSM
- Enables:
  - Remote monitoring
  - Live video streaming

o Command and control from base station

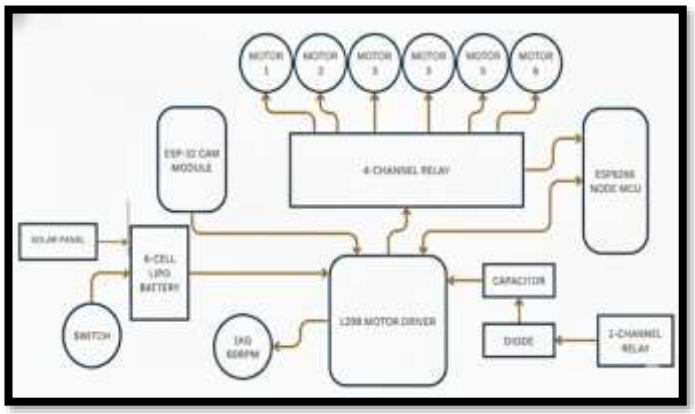

Fig.1 Block Diagram of Implemented Work

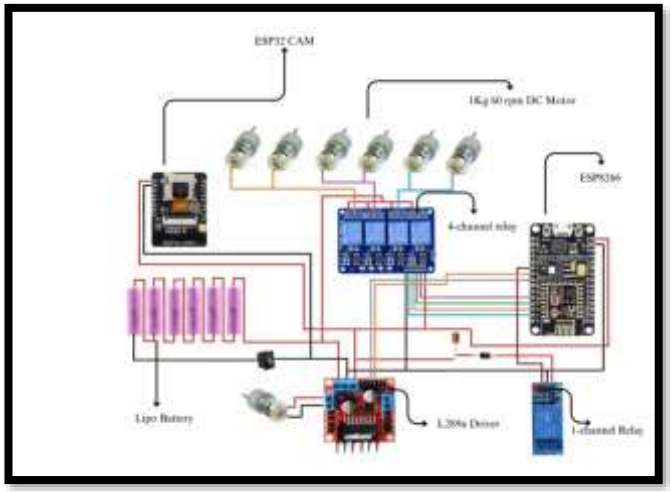

Fig.2 Diagram indicating various components of smart solar robot

3.0 Working of Robot: The robot uses a solar panel to convert sunlight into electrical energy using the principle of Photovoltaic Effect. This energy is regulated through a charge controller and stored in a rechargeable battery. The battery supplies power to all components even when sunlight is not available. The central controller consisting of software like Arduino Ide (MCU) acts as the brain of the robot. It continuously process data programming Camera Module is used for capturing live videos for surveillance. Motors are controlled through a motor driver module. Based on input commands given through mobile, Robot moves forward, backward, left, or right according to requirement and avoids obstacles automatically and can patrol a predefined path. The robot transmits data using Wi-Fi (ESP8266 and ESP32camera).

• **4.0 Hardware Description:** The smart solar robot equipped with several hardware components which are described under following section with specifications.

• **4.1 Solar Panel:** A solar panel is a device that converts sunlight into electricity by using multiple solar modules that consist of photovoltaic (PV) cells. Capacity of 5W-12W

Fig.3 Solar Panel

4.2 DC Geared motor: DC Motor is a compact electromechanical actuator designed for applications that demand controlled low speed and reliable torque output. Operating typically on 6-12 V DC, this motor converts electrical energy into smooth rotational motion through an integrated gear reduction system.

Fig.4 DC Motor

4.3 Microcontroller (ESP8266): is a low-cost, high-performance Wi-Fi microcontroller module developed by Systems, engineered to enable seamless Internet of Things connectivity. It integrates a 32-bit Ten silica L106 microprocessor, operating at 80 MHz.

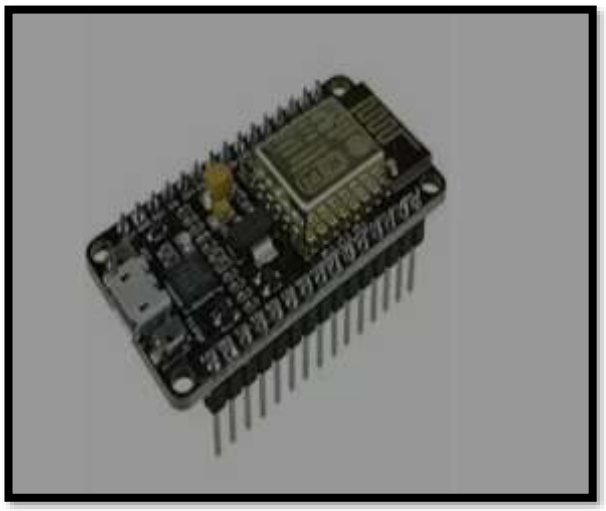

Fig 5 ESP8266 Microcontroller

4.4 Vision Module (ESP32): is a compact, low-cost embedded vision module developed by Systems, designed to deliver Wi-Fi and Bluetooth-enabled image processing in resource constrained environments. It is powered by the ESP32 dual-core 32-bit microcontroller, operating at up to 240 MHz.

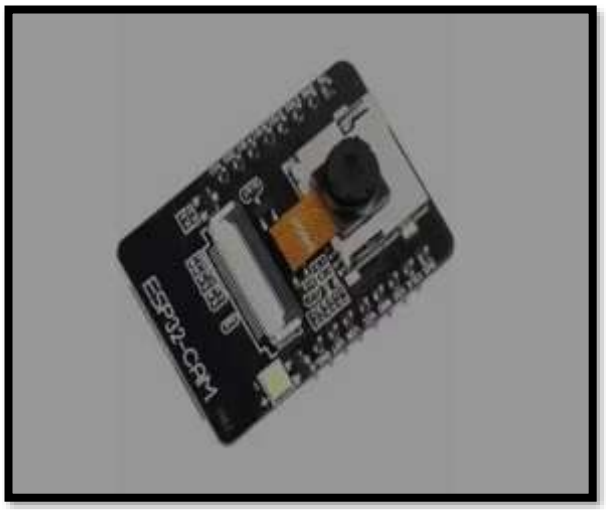

Fig.6 ESP32 Vision Module

4.5 Lithium Polymer battery: A rechargeable battery commonly used in drones, RC cars, robotics, and other portable electronics 6 batteries with 2.7 Volts each.

Fig.7 Lithium Polymer(LIPO) Battery

5.0 Results and Discussion: The fabricated smart solar robotot achieved an operation time of (1-2 hrs). Performed continuousss surveillance and transmitted obtained data to control te monitoring area. Solar panel charged the battery efficiently in sunlight within 6 hours. System worked well during daytime and depended on weather conditions. Provided limited operation during night or low sunlight. Camera enabled real-time monitoring. Various operations of robots controlled with mobi-le le and achieved good response.

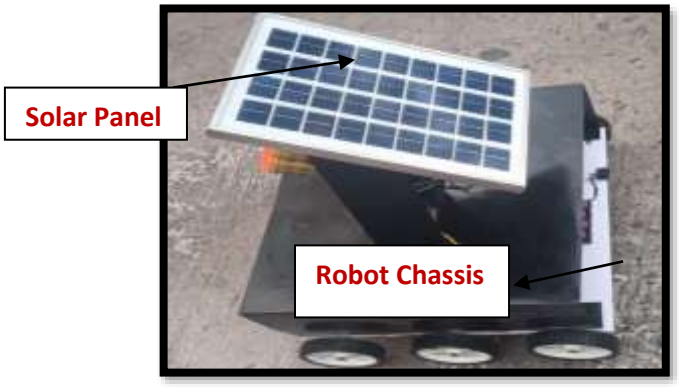

Fig.8 Smart Solar Robot

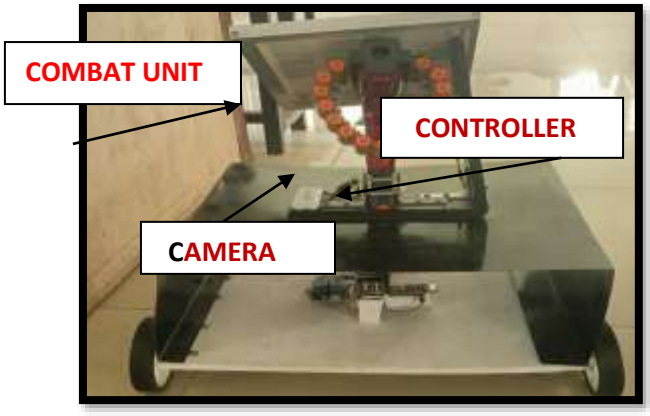

Fig.9 Smart Solar robot with combat unit

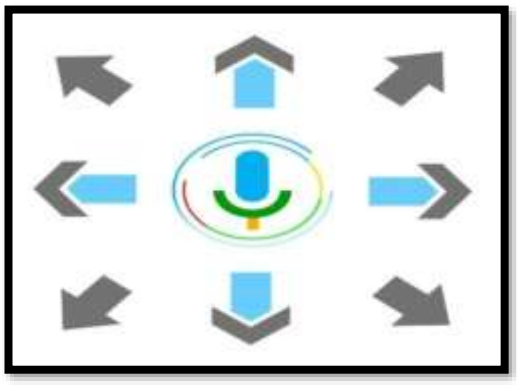

Fig.10. Various movements of Robot along with direction of firing using mobile App

6.0 Conclusions: Based on the working of smart solar robot the conclusions can be drawn are. The smart solar defence robot successfully designed and implemented. The robot its goaachieved its goal of combining solar energy with survellia- eillance for defence applications. Robot performed real-time mon monitoring and useful for security in restricted or remote areaareas.Low maintenance and operational cost. The system pro proved that solar-powered robotic defence solutions are prapractical and promising for future security applications.

7.0 Future scope of Work: Implementing Artificial Inte- intelligence (AI) and Machine Learning for advanced decdecision making. Enable automatic threat detection (humans, weapons, suspicious activity).Use high-efficiency sola solar panels for better energy generation. Improve detdetection accuracy in fog, rain, and darkness. Connect rob robot to Internet of things (IOT) platforms for remote access and data storage. Add GPS tracking for real-time location monitoring. Use thermal cameras, night vision, and radar sensors.

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