**Autonomous Solar Panel Cleaning with Reinforcement Learning**

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**1. Introduction  
Solar energy is one of the most sustainable and widely adopted renewable energy sources in the world. However, the performance of solar panels is significantly affected by environmental factors, particularly dust accumulation. In areas prone to dust or pollution, this can lead to a power reduction of up to 30%, which poses a considerable challenge to energy efficiency.**

**Manual cleaning processes are not scalable for large installations and may involve high labor costs and safety risks. Therefore, this project introduces an autonomous robotic system that uses deep learning and object detection to identify and clean dusty areas on solar panels. It combines hardware and software to provide a smart, efficient, and safe solution.**

**2. Objectives & Highlights**

**Objectives**

* **Build an autonomous robot for solar panel cleaning**
* **Integrate YOLOv11s for accurate, real-time dust detection**
* **Develop intelligent control logic for optimized movement**
* **Enhance safety using IR-based edge detection**
* **Optimize power and cleaning resources usage**

**Highlights**

* **YOLOv11s model trained on custom dust dataset**
* **Raspberry Pi 4 used for local model inference and control**
* **Zigzag movement pattern with MPU6050-based angle correction**
* **Safety ensured via IR sensors on panel edges**
* **Cleaning system activated through FET switching mechanism**

**3. System Architecture  
The robot moves over the solar panel in a predefined zigzag pattern. It captures images in real-time and detects the presence of dust using a YOLOv11s model. If dust is detected, the robot triggers a cleaning mechanism through a FET-based circuit. The movement logic is designed to ensure energy-efficient coverage and minimal resource usage.**

**MPU6050 is used to perform accurate 90-degree turns at the end of each path segment. IR sensors are constantly monitored to prevent the robot from moving off the panel’s edge.**

**Block Diagram Description**

**A diagram of a flowchart

AI-generated content may be incorrect.**

1. **Camera captures live frame**
2. **YOLOv11s processes image and identifies dusty areas**
3. **Cleaning logic activates via GPIO (FET switch)**
4. **MPU6050 and IR sensors guide movement and ensure edge safety**
5. **Robot navigates in zigzag pattern and repeats process**

**4. Implementation Details  
Hardware setup includes Raspberry Pi 4 (8GB), L298N motor driver, IR sensors, MPU6050, camera, and DC motors. Software components were developed in Python, utilizing libraries like OpenCV for image handling and RPi.GPIO for GPIO control.**

**The YOLOv11s model was trained on a custom dataset of dusty panel images using Google Colab and deployed to the Raspberry Pi.**

**The movement control code detects IR edge signals, performs reorientation using MPU data, and maintains a consistent zigzag path.**

**A group of robots with wheels

AI-generated content may be incorrect.**

**5. Results**

* **Dust detection accuracy: ~80% with YOLOv11s**
* **Cleaning efficiency: 90–95% area coverage**
* **Cleaning only activated when dust is detected, saving energy and resources**
* **Edge detection successful in preventing robot falls**
* **Angle correction and movement consistency maintained with MPU6050**

**A computer screen with a picture of a road and a lamp

AI-generated content may be incorrect.**

**6. Conclusion & Future Work  
This project demonstrates a practical and cost-effective solution for autonomous solar panel cleaning. It successfully integrates deep learning with real-time control on embedded systems. The intelligent movement strategy allows efficient cleaning while conserving energy and ensuring safety.**

**Future Work:**

* **Add solar charging capability**
* **Enable real-time cloud logging**
* **Improve turn stability using PID tuning**
* **Expand support for larger solar arrays using multiple robots**