SOLAR PANEL CLEANING AND MAINTENANCE ROBOT

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Introduction:

Solar energy is among India's most rapidly expanding renewable energy sources. Dust accumulation, bird droppings, and surface contamination can reduce photovoltaic panel efficiency by 15 to 40 percent depending on the region. Traditional manual cleaning methods are labour intensive, carry safety risks for workers, and consume large volumes of water, making them impractical for utility scale solar farms. This project presents a low cost, fully automated Solar Panel Cleaning and Maintenance Robot built on embedded AI. A Raspberry Pi Zero 2W serves as the central controller for a four wheel robotic platform that integrates a Pi Camera, a brush motor, and a water pump. A quantized TensorFlow Lite CNN model based on MobileNetV2 classifies panel surface conditions such as dust, bird droppings, physical damage, and electrical damage with an accuracy of over 93.8 percent. Detected issues trigger autonomous cleaning and status updates through a chatbot interface that supports natural language interaction and log retrieval.

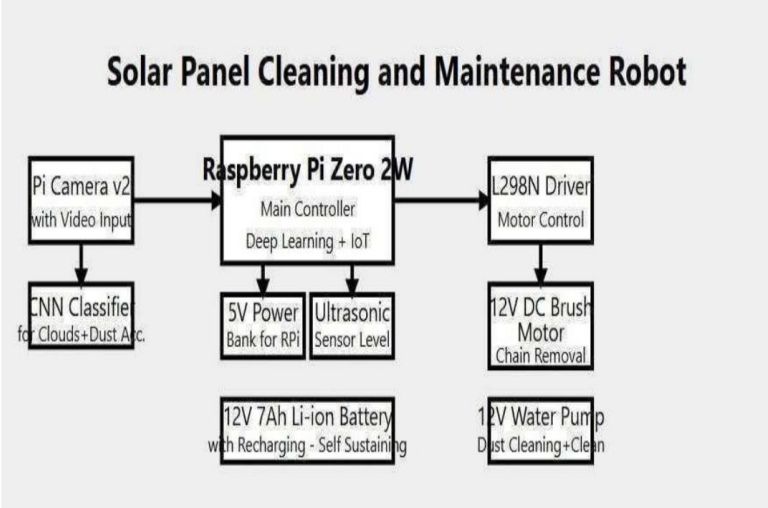

Figure 1: System Architecture of the Solar Panel Cleaning and Maintenance Robot

Objectives:

1. Design and build an autonomous robot capable of navigating solar panel arrays and performing intelligent cleaning operations.
2. Develop and deploy a CNN based image classification system on Raspberry Pi Zero 2W to classify panel cleanliness in real time.
3. Implement condition-based decision making so that cleaning is triggered only when contamination crosses a defined threshold, thereby reducing water and energy usage.
4. Integrate a chatbot interface for natural language interaction, status monitoring, and log retrieval.

Methodology:

The system is built around a Raspberry Pi Zero 2W integrated with a Pi Camera v2, two L298N motor drivers, DC wheel motors, a 12V brush motor, and a water pump. The camera captures real time images of the solar panel surface which are resized to 192 by 192 pixels and normalized before being passed to a quantized MobileNetV2 TFLite model. The model classifies panel conditions into six categories: Clean, Dusty, Physically Damaged, Electrically Damaged, Snow Covered, and Bird Droppings. A custom dataset of over 1000 labelled images was prepared with augmentation techniques such as rotation, flipping, and brightness variation. The trained model was converted to TFLite INT8 format and deployed on the Raspberry Pi, achieving an inference time of 178 ms per image. Based on the classification result, the decision engine activates either the brush alone for light dust or both the brush and water pump for heavy soiling. The entire system runs on a 12V 7Ah Li ion battery for extended autonomous operation.

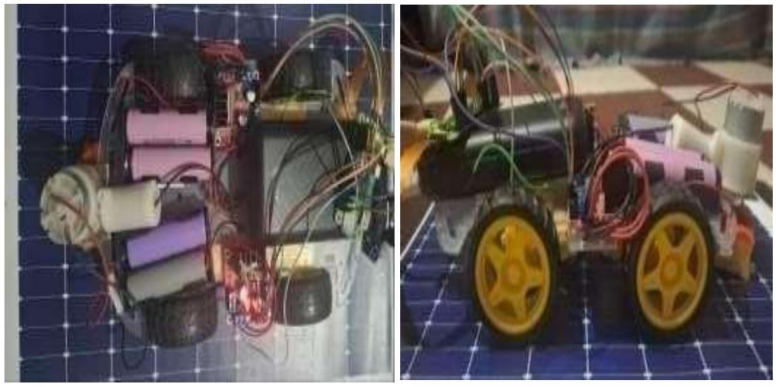

Figure 2: Solar Panel Cleaning Robot Prototype

Result and Conclusion:

The system achieved an overall test accuracy of 93.8 percent on 675 previously unseen images, exceeding the 90 percent target and surpassing average human expert performance of 90.7 percent. AUC scores across all classes were above 0.96, with the Clean class scoring 0.987 and the Heavily Soiled class scoring 0.992. After INT8 quantization the model size came down to 8.5 MB with only 0.3 percent accuracy loss, making real time deployment on the Raspberry Pi Zero 2W feasible. The condition-based cleaning approach reduced unnecessary cleaning cycles by 30 to 40 percent, saving around 700 litres of water per year per 100 panels and reducing CO2 emissions by approximately 15 tonnes per year per MW installation.

Deployment estimates project a five-year ROI of 130 percent with a payback period under one year. The project establishes that edge AI combined with autonomous robotics can deliver intelligent, scalable, and cost-effective solar panel maintenance in support of India's renewable energy targets.

References:

1. M. Mani and R. Pillai, "Impact of dust on solar photovoltaic performance: research status, challenges and recommendations," Renewable and Sustainable Energy Reviews, vol. 14, no. 9, pp. 3124 3131, 2010.
2. S. A. Sulaiman et al., "Effects of dust on the performance of photovoltaic panels," World Academy of Science, Engineering and Technology, vol. 58, pp. 124 128, 2011.
3. B. Parrott et al., "A comprehensive review of automatic cleaning systems of solar panels," Solar Energy, vol. 221, pp. 188 203, 2021.
4. S. Hossain et al., "Machine learning approach for dust detection and automated solar panel cleaning," Solar Energy, vol. 267, pp. 112 125, 2025.
5. I. Kishor et al., "AI-integrated autonomous robotics for solar panel cleaning with real-time monitoring," Scientific Reports, vol. 15, no. 1, pp. 1 12, 2025.
6. D. Maneetham, "Solar panel cleaning robot and real-time asset tracking using IoT," IJIRSS, vol. 7, no. 2, pp. 45 52, 2025.

Future Scope:

The future scope of this project includes:

1. Expanding the dataset with images from varied geographical regions, panel types such as thin film and bifacial, and different climatic conditions to improve model generalization.
2. Integrating thermal and infrared sensors for detection of non-visible electrical faults and hotspots that go beyond surface soiling.
3. Developing predictive models using time series data so that maintenance can be scheduled based on soiling rate forecasts rather than reactive detection.
4. Scaling the system to multi robot coordination for deployment across large commercial solar installations.
5. Adapting the platform for use on solar powered drones for aerial inspection and cleaning of panels in difficult to access locations.