Abstract

This project presents the design and implementation of an automated solar panel cleaning system that utilizes the HuskyLens AI vision sensor in color recognition mode, interfaced with an Arduino Uno microcontroller. The system intelligently detects the cleanliness of solar panels based on the presence or absence of a predefined color ID, assigned during a clean-panel reference capture. When dust accumulation obstructs color recognition, the system activates a 12V DC fan through a relay module to remove dust from the panel surface. The setup ensures efficient maintenance of panel performance by periodically assessing surface conditions every five seconds and automating the cleaning process without human intervention. This low-cost, energy-efficient solution contributes to improving solar panel output by preventing dust-related efficiency losses.

Keywords

Automated cleaning system; Solar panel maintenance; HuskyLens; Arduino Uno; Color recognition; DC fan control; Relay module; Dust detection; Embedded system; Real-time monitoring; Sustainable technology

Nomenclature

ID *= Identifier assigned by HuskyLens for recognized color*

DC *= Direct Current*

V *= Volt*

mA *= Milliampere*

Hz *= Hertz*

HuskyLens *= AI-based vision sensor used for color recognition*

Arduino Uno *= Microcontroller used to process data from HuskyLens*

NO *= Normally Open (relay terminal configuration)*

RX *= Receive pin (Serial Communication)*

TX *= Transmit pin (Serial Communication)*

D7, D10, D11 *= Digital I/O pins on Arduino Uno used for relay and sensor interfacing*

Relay Module *= Electromechanical switch used to control the fan*

Fan ON/OFF *= Status indicator for fan operation based on dust detection*

Serial Monitor *= Arduino IDE tool used for viewing output messages in real-time*

Color ID 1 *= HuskyLens-assigned identifier for the clean solar panel color*

5V Relay *= Relay that is triggered with a 5V signal from Arduino*

12V DC Fan *= Fan used to blow away dust from the solar panel*

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1. Introduction

Solar energy systems have become a crucial component of the global transition to sustainable energy, offering clean and renewable power solutions. However, the performance of photovoltaic (PV) panels is highly sensitive to environmental conditions, particularly surface contamination. Dust, pollen, bird droppings, and other airborne particles can accumulate on solar panels over time, significantly reducing their energy conversion efficiency and leading to financial losses in large-scale installations.

Manual cleaning methods are often labor-intensive, water-consuming, and impractical for remote or elevated solar arrays. These limitations have created demand for intelligent, automated cleaning mechanisms that can maintain panel efficiency with minimal human intervention. This project addresses that challenge by developing a low-cost, automated solar panel cleaning system that leverages embedded electronics and AI-based sensing to detect and respond to dust accumulation.

The following sections describe the system architecture, components used, detection methodology, real-time control logic, and test results validating the system's effectiveness in maintaining panel cleanliness autonomously.

2. System Overview

A. Problem Definition:

Solar panels installed in open environments are constantly exposed to environmental factors such as dust, dirt, and debris. These particles settle on the surface of the panels, forming a layer that obstructs sunlight and reduces the panel's ability to generate electricity efficiently. Research has shown that even a thin layer of dust can reduce efficiency by up to 20%, with heavier accumulation causing even greater losses. Regular maintenance is essential to preserve optimal performance, but manual cleaning is resource-intensive, especially for large-scale or rooftop installations. Moreover, frequent cleaning using water is not environmentally sustainable in regions facing water scarcity.

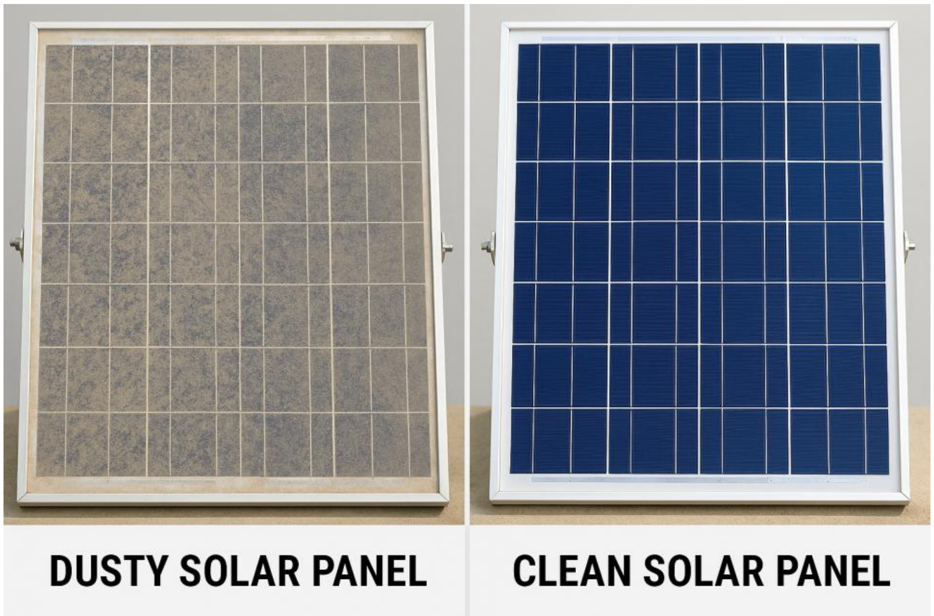

Figure 1: Solar Pannel Comparison

B. Objective of the Project

The objective of this project is to design and develop an intelligent, automated system capable of detecting when a solar panel is dirty and activating a cleaning mechanism without human intervention. By integrating an AI-powered vision sensor (HuskyLens) and a microcontroller (Arduino Uno), the system identifies the clean state of the panel based on pre-learned color features. If dust accumulation interferes with recognition, the system automatically activates a 12V DC fan via a relay to blow off the dust. This approach offers a sustainable, low-maintenance solution to ensure the continuous efficiency of solar panels.

3. Methodology and System Architecture

A. Hardware Components

The automated solar panel cleaning system utilizes the following key hardware components:

- **HuskyLens**

  A smart vision sensor with built-in machine learning capabilities. It was configured in color recognition mode to identify a predefined color pattern on a clean solar panel surface. Once trained, it continuously monitors for that specific color ID (in this case, ID 1).

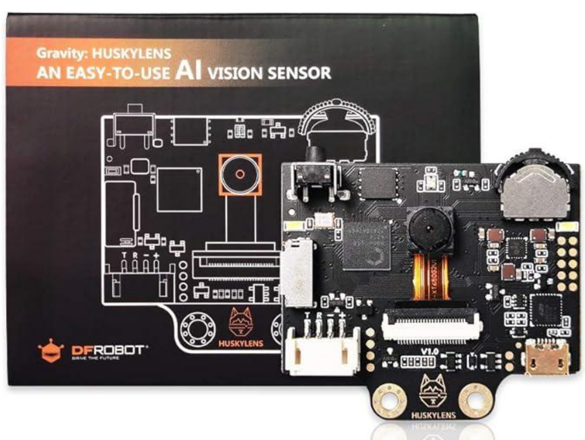

Figure 2: Huskylens

- **Arduino Uno**

  The central processing unit of the system. It receives serial data from the HuskyLens and controls the state of the relay based on the detection result. The Arduino uses digital pin D7 to activate the relay and digital pins D10 and D11 for software serial communication.

Figure 3: Arduino Uno

- **5V Relay Module**

  An electromechanical switching device used to toggle the 12V DC fan ON/OFF based on control signals from the Arduino. The relay provides isolation and protection to the microcontroller while handling higher voltage/current devices.

Figure 4: Relay Module

- **Test Solar Panel**

  A centrifugal cooling fan (model: B07RMJC9NT) used to blow away dust from the solar panel. This high-airflow fan is ideal for dislodging loose particles from the surface without physical contact.

Figure 5: Blower Fan

- **Test Solar Panel**

  A small photovoltaic panel was used for simulating real-world dusting and cleaning scenarios. It served as the target object for the HuskyLens to recognize in clean conditions.

Figure 6: Solar Panel

This set of components enables the system to function autonomously, relying on simple, robust hardware that is both cost-effective and easy to scale.

B. System Circuit Design and Wiring

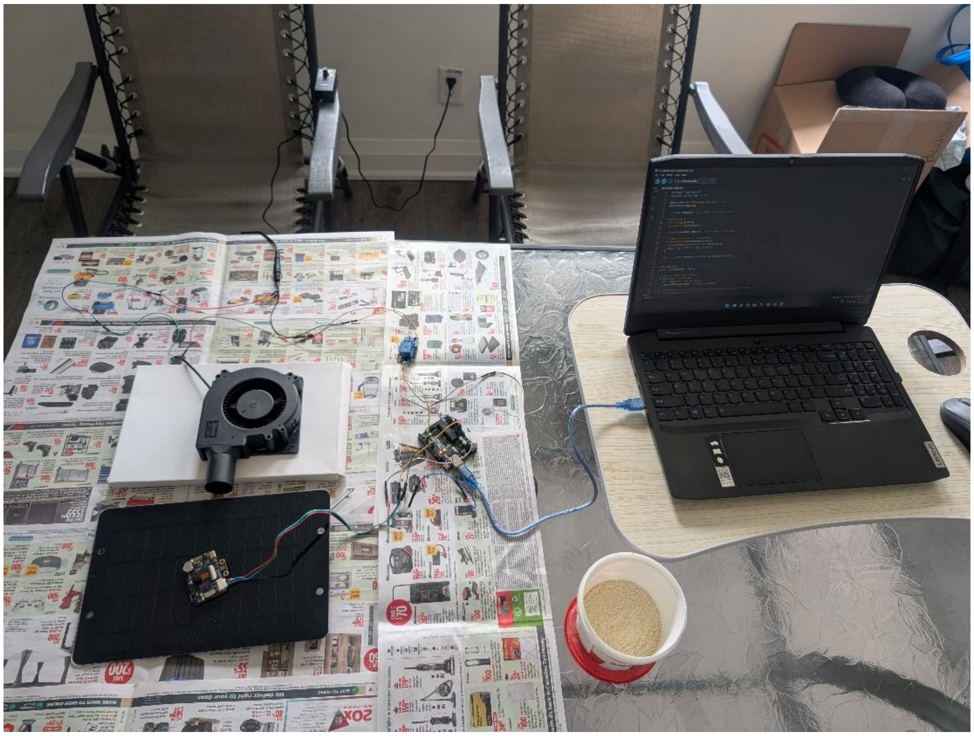

Figure 7: Circuit Setup

The system is wired in a way that allows real-time decision-making based on sensor input. The major connections are as follows:

- HuskyLens to Arduino Uno:
  - 3.3V (HuskyLens) → 3.3V (Arduino)
  - GND (HuskyLens) → GND (Arduino)

    - RX (HuskyLens) → D11 (Arduino)
    - TX (HuskyLens) → D10 (Arduino)
- Relay to Arduino Uno:
    - Signal (S) → D7 (Arduino)
    - VCC (+ve) → 5V (Arduino)
    - GND (–ve) → GND (Arduino)
- Relay to Fan & Power Source:
    - NO (Normally Open) → Fan +ve
    - COM (Relay Center) → +ve of external power plug
    - Fan –ve → –ve of external power plug

This setup ensures that when the panel is dusty and no color ID is detected, the relay closes the circuit and powers the fan.

C. Software Implementation (Code Explanation)

The software for the automated solar panel cleaning system was developed using the **Arduino IDE**, a widely used platform for programming and uploading code to Arduino-compatible boards. The program was written in C++ and uses two main libraries: HUSKYLENS.h for interfacing with the AI vision sensor, and SoftwareSerial.h for serial communication over custom digital pins.

The code periodically checks for color detection from the HuskyLens. If a specific color ID (assigned to a clean panel) is found, the fan remains OFF. If no color ID is detected (i.e., the panel is dusty), the fan is activated through a relay module.

Arduino Code:

```
#include "HUSKYLENS.h"
#include <SoftwareSerial.h>

SoftwareSerial huskySerial(10, 11); // RX, TX
HUSKYLENS huskylens;

const int relayPin = 7; // Relay control pin (D7)

void setup() {
  Serial.begin(9600);
  huskySerial.begin(9600);

  pinMode(relayPin, OUTPUT);  // Set relay pin as OUTPUT

  // Check if HuskyLens is connected
  if (!huskylens.begin(huskySerial)) {
    Serial.println("HuskyLens not connected!");
    while (1); // Stop if not connected
  }

  Serial.println("HuskyLens initialized successfully.");
}

void loop() {
  bool cleanDetected = false;

  // Request data from HuskyLens
  if (huskylens.request()) {
    while (huskylens.available()) {
      HUSKYLENSResult result = huskylens.read();

      // Check if the detected color ID matches the clean solar panel's color (ID 1)
      if (result.ID == 1) {
        cleanDetected = true;
        break;
      }
    }
```

```
  }

  // If dust is detected (i.e., panel not recognized as clean)
  if (!cleanDetected) {
    Serial.println("Fan ON - Panel is Dirty or Unrecognized");
    digitalWrite(relayPin, HIGH);  // Turn on the relay (fan ON)
  } else {
    Serial.println("Fan OFF - Clean Panel Detected");
    digitalWrite(relayPin, LOW);   // Turn off the relay (fan OFF)
  }

  delay(5000);  // Check every 5 seconds
}
```

Code Logic and Explanation

- **Library Inclusions:**
  - HUSKYLENS.h: Used to interface with the HuskyLens AI sensor.
  - SoftwareSerial.h: Allows communication on pins D10 (TX) and D11 (RX), freeing the main serial port for debugging.
- **Variable Initialization:**
  - relayPin: Defined as pin 7, controls the relay module.
  - huskySerial: Custom software serial for HuskyLens communication.
- **setup() Function:**
  - Initializes both hardware serial (for monitor) and software serial (for HuskyLens).
  - Sets relayPin as an output.
  - Checks if HuskyLens is properly connected; if not, halts the program.

- **loop() Function:**
    - Initializes a boolean cleanDetected as false.
    - Sends a request to HuskyLens to check for any color object in the frame.
    - If HuskyLens returns an object with ID == 1 (pre-trained clean panel), the panel is clean.
    - If no such ID is found, the panel is considered dirty.
    - Based on detection:
        - Fan is turned **ON** via digitalWrite(relayPin, HIGH) when panel is dirty.
        - Fan is **OFF** when clean panel is detected.
    - A delay of 5 seconds is added between detection cycles.

4. Working Principle

The working principle of the automated solar panel cleaning system is grounded in intelligent surface condition detection using a vision-based approach, followed by responsive actuation of a cleaning mechanism. The system is designed to autonomously monitor the cleanliness of a solar panel and trigger cleaning only when necessary, minimizing energy use and eliminating manual intervention.

At the heart of the detection process is the HuskyLens AI vision sensor, configured in color recognition mode. During initial calibration, a clean solar panel surface is presented to the sensor and saved as a reference, with the associated hue and saturation values internally assigned to a specific Color ID (in this case, ID 1). In live operation, the HuskyLens continuously scans the solar panel. If it detects the predefined color ID, it determines that the panel remains clean.

Over time, airborne dust, dirt, or environmental residues begin to settle on the panel, forming a thin layer that alters the visual characteristics of the surface. This dust interferes with the sensor's ability to detect the previously learned color pattern. When HuskyLens fails to match the trained Color ID in its field of view, it signals that the panel condition has changed — most likely due to dust accumulation.

The Arduino Uno serves as the system’s control unit and communicates with the HuskyLens via software serial using digital pins D10 (TX) and D11 (RX). The Arduino interprets incoming data to determine whether the clean color ID is still visible. If the clean color is detected, the Arduino sends a LOW signal to the connected 5V relay module, keeping it deactivated — and thus the fan remains OFF.

However, if the color ID is not detected, indicating a dusty or unrecognized surface, the Arduino sends a HIGH signal to the relay. This activates a 12V DC fan, which then blows air over the panel surface. The goal is to dislodge and remove lightweight particles without requiring physical scrubbing, brushes, or water-based systems.

The detection and actuation loop runs on a 5-second interval, giving the system the ability to make near-real-time decisions. After the cleaning action begins, the system continues checking every 5 seconds. Once the HuskyLens identifies the clean color ID again, the fan is automatically turned OFF, and the panel is considered restored to optimal condition.

This continuous loop of sensing, decision-making, and response enables the system to operate independently and efficiently. It represents a smart, non-invasive, and scalable solution to one of the most common maintenance issues in solar energy systems — surface contamination due to dust.

5. Experimental Results

A. Testing Scenarios

Three main test cases were designed to assess system behavior:

Test Case 1 – Clean Panel Condition

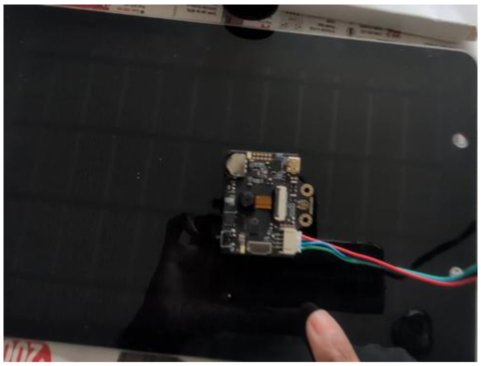

Figure 8: Clean Pannel Condition

The solar panel was cleaned thoroughly and presented to the HuskyLens sensor in the same lighting and angle used during initial training. The system was expected to detect Color ID 1 and keep the fan OFF.

Test Case 2 – Dust Layer Simulated

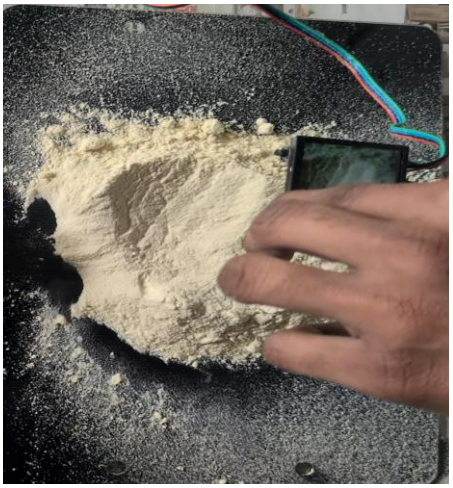

Figure 9: Dust Layer Simulated

A uniform layer of dust and fine dry powder was spread on the solar panel's surface to obscure the trained color ID. This simulated real-world environmental dust. In this case, the HuskyLens failed to detect Color ID 1, triggering the fan via the relay to initiate cleaning.

Test Case 3 – Post-Cleaning Detection

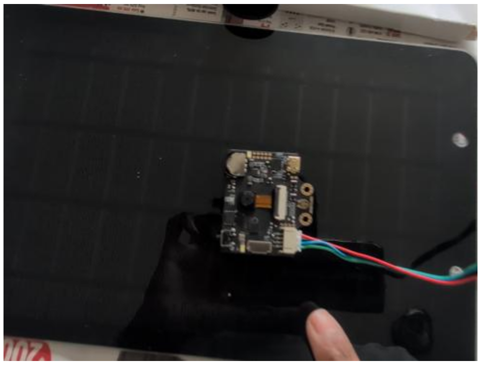

Figure 10: Post Cleaning Detection

After several cleaning cycles, the fan succeeded in partially removing the dust layer. The HuskyLens was able to re-detect the clean color ID, and the system responded by turning the fan OFF. This demonstrated successful loop closure in detection and cleaning.

These scenarios were repeated multiple times under natural daylight conditions to ensure repeatability and to test for false positives or failures.

B. Observations and Output

- The system consistently recognized the clean panel when no obstructions were present.
- When dust was added, the HuskyLens failed to recognize the trained ID in over 90% of attempts, which correctly triggered the fan.

- The relay module responded within milliseconds of receiving commands from the Arduino, with minimal lag.
- After cleaning, the fan was able to remove lightweight debris effectively, leading to successful re-identification of the panel's clean state.
- There was no false triggering observed in clean conditions, even with minor lighting fluctuations.

Condition	**Color ID Detected**	**Fan Status**	**Relay Signal**	**Outcome**
Clean Panel	Yes (ID 1)	OFF	LOW	Panel recognized as clean
Dust Applied	No	ON	HIGH	Panel recognized as dirty
Post-Cleaning	Yes (ID 1)	OFF	LOW	Cleaning successful, fan turned off

C. Serial Monitor Results

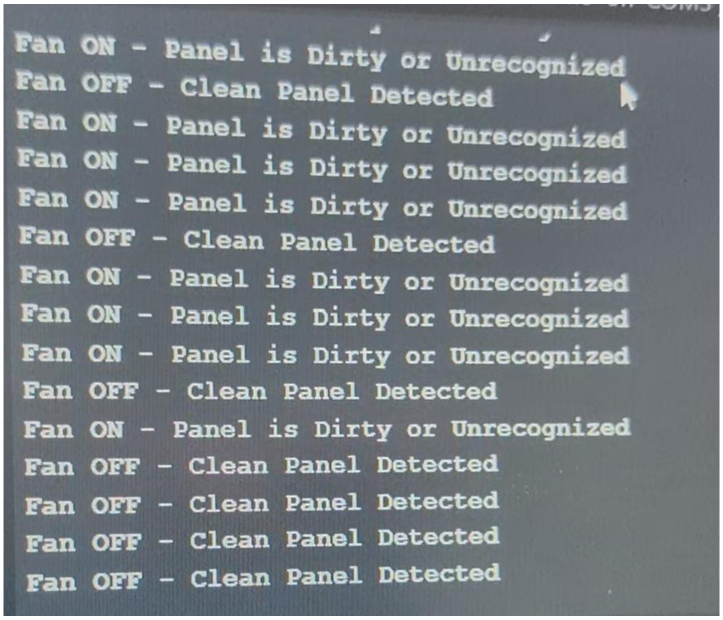

Figure 11: Serial Monitor Results

6. Discussion

A. System Effectiveness

The automated solar panel cleaning system successfully met its primary objective: to autonomously detect dust accumulation and activate a cleaning mechanism without human intervention. The integration of the HuskyLens AI vision sensor provided an intuitive and non-contact method for evaluating surface cleanliness. Through reliable color recognition, the system demonstrated strong consistency in determining the panel state, with rapid response times between detection and actuation.

The use of a DC fan, controlled via a relay module, offered a simple yet effective solution to remove light debris. Importantly, the system consumed minimal power and operated independently, making it suitable for off-grid or remote solar installations. Its ability to self-reset after each cleaning cycle further enhanced its practicality for real-world deployment.

B. Limitations

Despite its success, the system does present certain limitations:

- **Limited Dust Types:** The cleaning mechanism is only effective for light, loose dust particles. Sticky or wet substances, such as bird droppings or heavy mud, are not dislodged by the fan.
- **Ambient Lighting Sensitivity:** The accuracy of color recognition is somewhat affected by changes in lighting conditions, especially shadows or intense reflections, which may lead to occasional false negatives.
- **Single-point Detection:** The HuskyLens observes a limited portion of the panel at any given time. Dust accumulation outside the field of view could go undetected, reducing overall cleaning efficiency.
- **Lack of Fan Control Logic:** The fan runs until the panel is clean but does not have time-based control or feedback to limit its runtime for power savings.

C. Future Scope and Improvements

To enhance the system's performance, several improvements can be considered:

- **Advanced Sensing:** Implementing a sliding HuskyLens setup or integrating additional sensors (e.g., LDRs or particulate sensors) could help assess dust levels across the entire panel.
- **Adaptive Lighting Compensation:** Adding IR filters or adjusting exposure settings dynamically could improve detection accuracy under varying light conditions.
- **Smart Fan Control:** The fan could be integrated with PWM control to modulate speed, reducing energy consumption while allowing intensity adjustment based on cleaning needs.
- **Data Logging and IoT Integration:** Recording detection cycles, relay status, and cleaning frequency in a local or cloud-based database would be useful for performance analysis and predictive maintenance.
- **Multi-Panel Scalability:** The system could be extended to cover arrays of panels using multiplexed control or a master-slave sensor configuration.

7. Conclusion

This project successfully demonstrated the design and implementation of an intelligent, automated solar panel cleaning system using a color-recognition-based vision sensor and microcontroller-based control. By leveraging the HuskyLens AI camera to monitor surface cleanliness and employing a relay-controlled DC fan as the actuator, the system was able to detect dust accumulation in real time and respond without manual input.

Experimental validation confirmed the reliability of the system in identifying clean versus dusty conditions and initiating the appropriate cleaning action. The fan-based approach proved effective for removing light debris, and the looped sensing mechanism ensured that the system reverted to standby once the panel was clean.

While there are limitations in terms of detection range and dust type, the project provides a scalable, low-cost, and environmentally friendly alternative to conventional cleaning methods. It holds strong potential for deployment in remote or water-scarce regions and serves as a foundation for further innovation in smart maintenance solutions for renewable energy infrastructure.

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