EcoVision: Automated Solar Panel Cleanliness Detection

Improving Energy Output Through Automated Soiling Detection

Solar panels lose efficiency when dirty, and manual inspections are slow and expensive. EcoVision uses advanced computer vision to automate soiling detection, ensuring optimal energy production.

By: David A. Suarez

EcoVision Data: What We Detect

Our system processes diverse image sources to classify panels as "clean" or "dirty," handling varied conditions with robust algorithms.

1

Binary Labels

Clean vs. Dirty (clear classification)

2

Image Sources

Fixed cameras and drone imagery

3

Real-World Variability

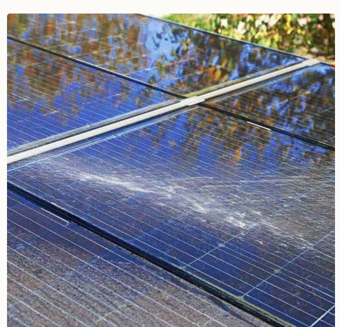
Adapts to lighting, angles, shadows, and glare

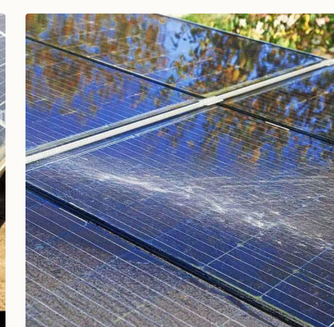
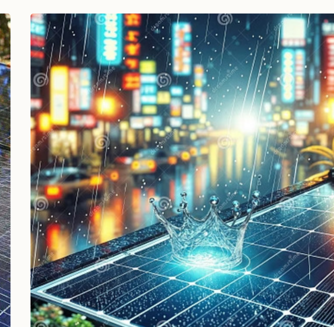
4

Noise Handling

Manages ambiguous cases like wet vs. dirty

Visual examples of our detection capabilities:

The Real-World Problem: Soiling Reduces Efficiency

Efficiency Loss

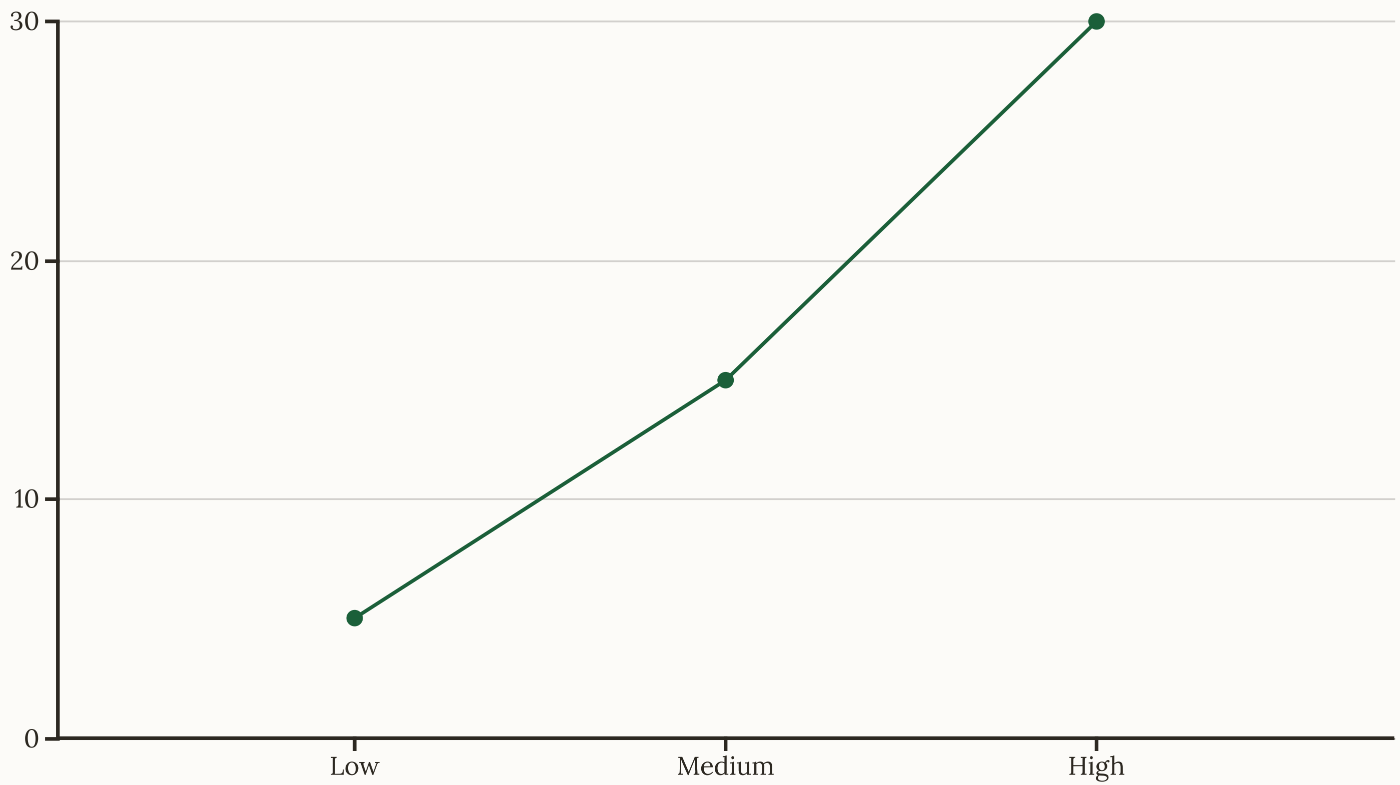
Soiling (dust, bird droppings, pollen, ash) reduces PV efficiency by 5–30% depending on region.

Decreased Yield

This directly impacts energy yield and revenue, accelerating degradation and creating hotspots.

Monitoring Gaps

Remote sites often lack reliable and consistent monitoring, exacerbating the problem.



Energy loss significantly increases with higher soiling levels, impacting overall plant performance.

Why This Matters: Stakeholders & Costs

Operators

Need accurate detection to guide cleaning schedules and optimize operations.

O&M Teams

Avoid wasting labor and water on unnecessary cleaning, maximizing efficiency.

Environmental

Minimizes unnecessary water use, especially critical in arid regions.

Grid/Utility

Dirty panels lead to reduced generation stability, affecting grid reliability.

Example Dataset & Detection Capabilities

Our system detects soiling through binary classification and optional segmentation.

1	2	3
Data Input Images from fixed cameras and drones are analyzed for clean vs. dirty labels.	**Variability Handled** The system accounts for lighting, angles, shadows, and glare for robust detection.	**Noise Reduction** Sophisticated algorithms minimize noise and handle ambiguous cases like wet surfaces vs. actual dirt.

System Outputs & Smart Usage

Primary Output

"Clean/Dirty" classification with confidence score.

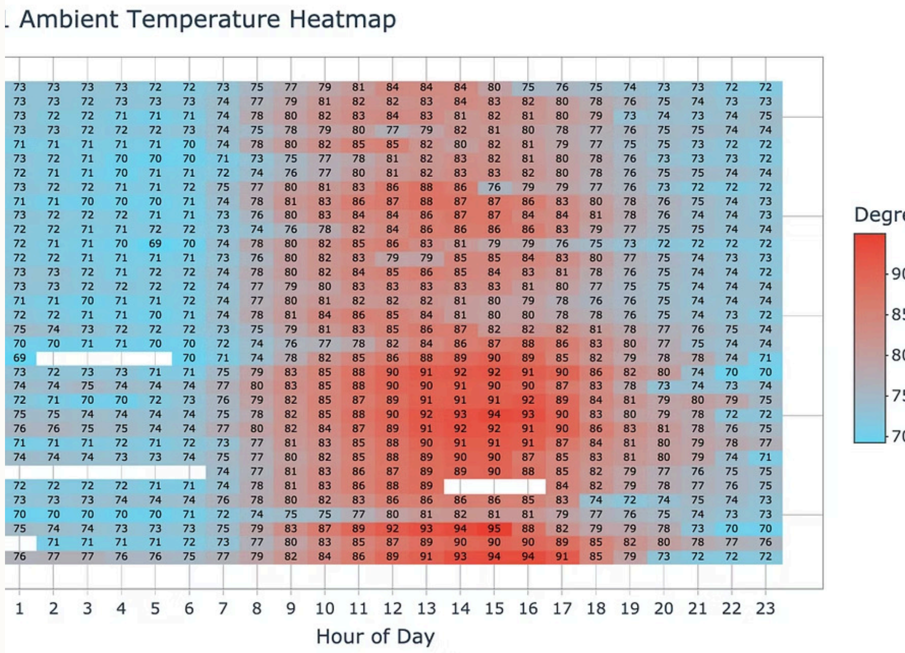
Optional Segmentation

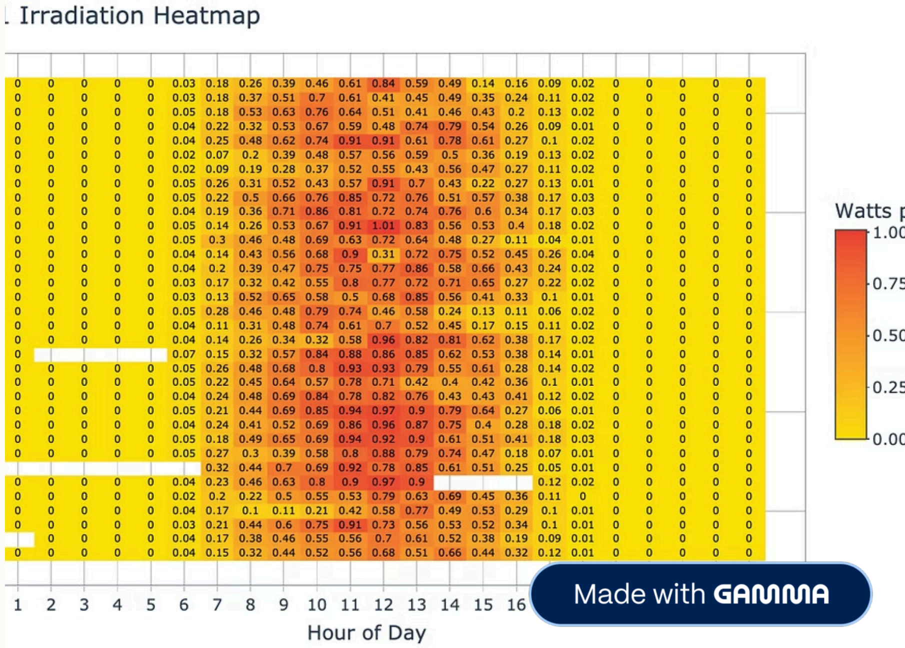
Detailed segmentation mask highlighting dirty regions.

Targeted Cleaning

Enables precise and efficient cleaning schedules.

Visualize overall panel health with a severity heatmap and track dirty panel percentages over time.





Challenges & Success Criteria

Overcoming Challenges

- Class imbalance and seasonal drift
- Glare and occlusions impact image quality
- Requires consistent retraining with new field data

Defining Success

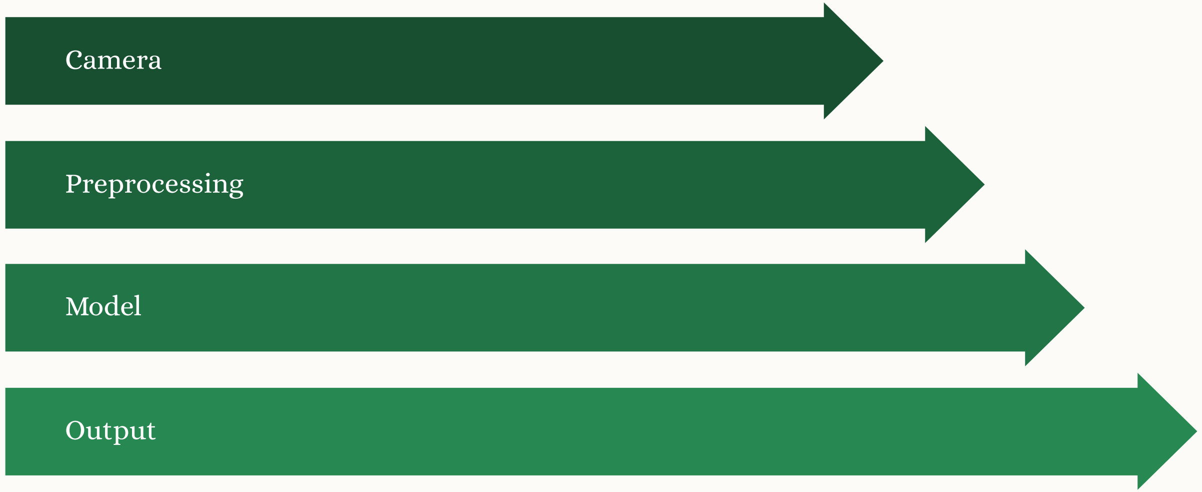
- >90% classification accuracy
- Low false negatives to ensure proper cleaning
- Month-long pilot and cross-season field validation

Accuracy	90%+	88%	High
Recall	95%+	92%	High
F1 Score	90%+	89%	High

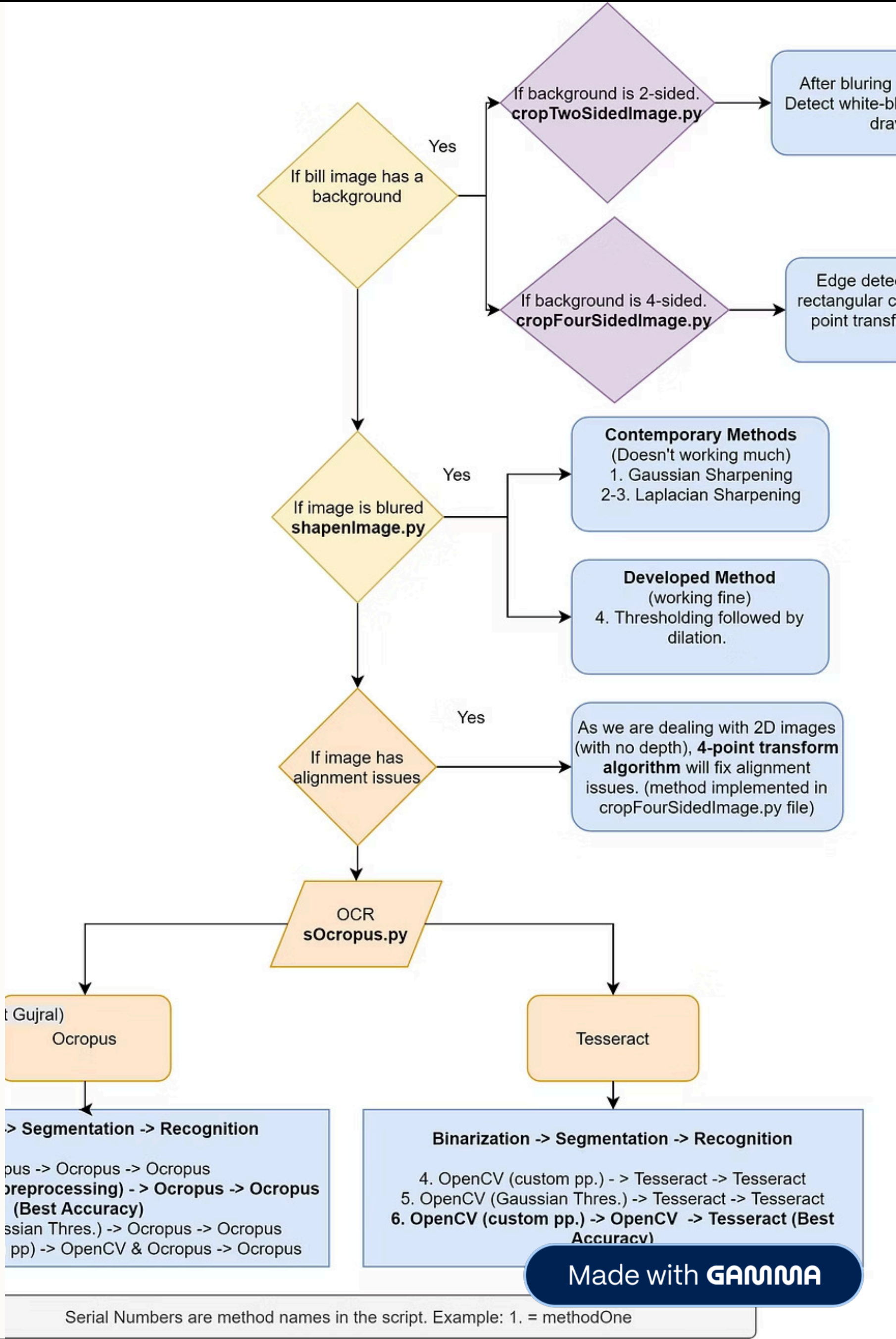
Our focus is on achieving high accuracy and recall for reliable operational impact.

Technical Pipeline Overview

A modular and robust system from data acquisition to cleaning recommendations.



The pipeline can be deployed on edge devices or in the cloud, offering flexible scalability.



Why AlexNet? High-Level Architecture

A proven CNN for image classification tasks.

Proven Performance

AlexNet is a classic CNN with strong performance for image classification.

Baseline Model

An excellent starting point for small to medium-sized datasets.

Core Structure

Combines convolutional, ReLU, pooling, and dense layers for robust feature extraction.

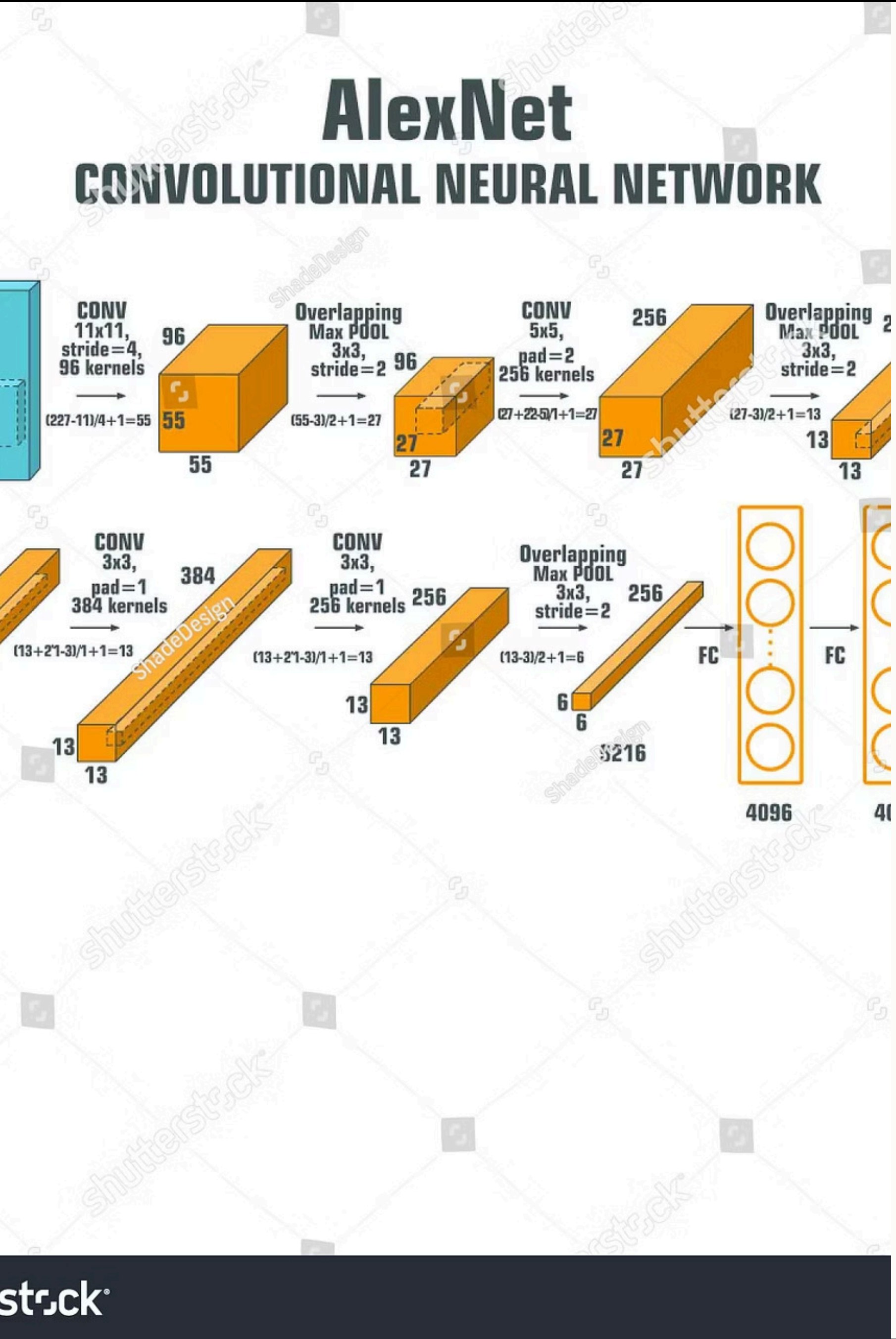
Input

Convolutions

Pooling

FC & Softmax

Input size is standardized to 227x227x3 RGB for optimal processing.



AlexNet Layer Breakdown

Key Layers

- **Conv1:** 11×11 filters, 96 channels, followed by pooling.
- **Conv2:** 5×5 filters, 256 channels, followed by pooling.
- **Conv3, Conv4:** 3×3 filters, 384 channels.
- **Conv5:** 3×3 filters, 256 channels, followed by pooling.

Output & Classification

- **FC Layers:** Three fully connected layers (4096 neurons each) for high-level feature combination.
- **Output:** Softmax layer for binary classification (Clean vs. Dirty).

This architecture efficiently extracts hierarchical features for accurate soiling detection.

Preprocessing & Data Integration

Image Preparation

Augmentation

Panel Cropping

Robust preprocessing is crucial for model generalization and performance in varied field conditions.

Preprocessing & Data Augmentation

Transforming raw images into optimal inputs for AlexNet, enhancing model robustness and accuracy.

Data Preparation

- Resize/Crop to 227x227 pixels
- Normalize using ImageNet means (for pretrained weights)
- Crop individual panels from wide images

Augmentation Techniques

- Flip (horizontal/vertical)
- Brightness/Contrast Jitter
- Slight Rotation
- Synthetic Dirt Overlays
- Shadow Augmentation

These steps ensure our model learns from a diverse and representative dataset.