

Motivating Use Case

The \$13B Problem

Foreign Object Debris (FOD) on runways poses a critical safety risk to aviation, costing the industry over **\$13 billion annually** in direct and indirect damages.



The Challenge:

Detecting small, low-contrast debris (nuts, bolts, wildlife) across vast runway surfaces under varying weather conditions.

Current Solutions:

Manual drive-by inspections are slow and error-prone. Radar systems are expensive and suffer from high false alarm rates.



Project Task Description

Formal Problem Statement

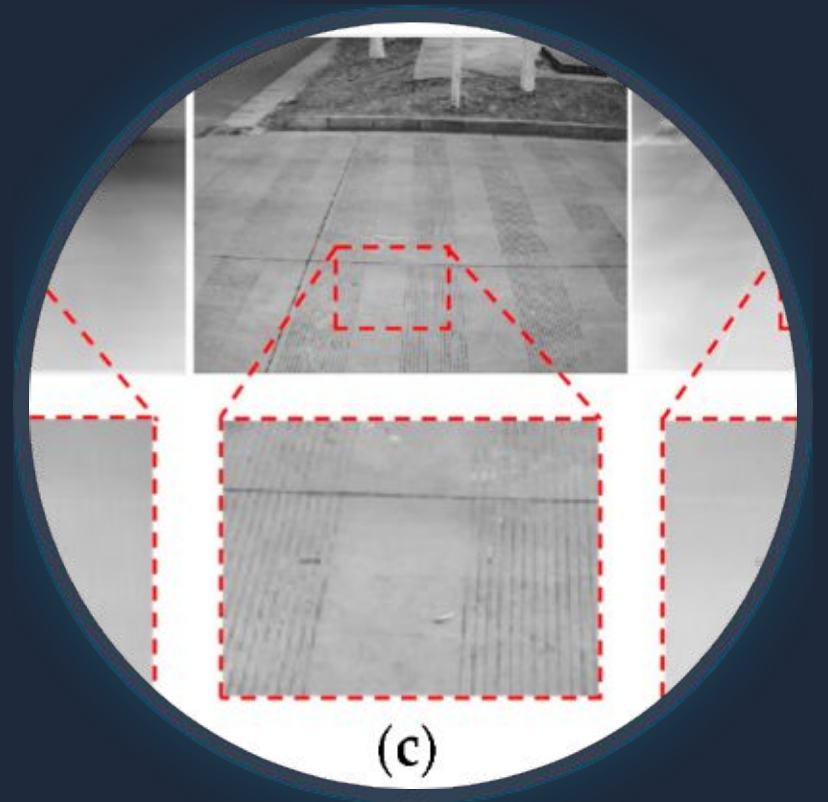
Develop an automated, end-to-end computer vision system to **detect**, **localize**, and **classify** runway hazards in real-time with high precision.

Input & Output

- **Input:** High-resolution RGB runway imagery (simulated drone/CCTV feed).
- **Output:** Bounding Box coordinates (x, y, w, h) and Class Label (e.g., "Metal", "Rubber", "Ice", "Oil Spills").

Project Novelty

Addressing the "data scarcity" bottleneck by utilizing a **Generative AI pipeline** to create a massive, diverse synthetic training dataset of rare hazard scenarios.



Models & Processing Pipeline



1. Generation

Stable Diffusion + ControlNet used to inpaint diverse debris onto clean runway backgrounds.



2. Labeling

Auto-Labeling pipeline leverages the generation masks to create pixel-perfect Ground Truth bounding boxes.



3. Training

Fine-tuning state-of-the-art detectors like **YOLOv8** or **Faster R-CNN** on the hybrid dataset.



4. Evaluation

Rigorous testing using **k-fold cross-validation** on a separate set of real-world benchmarks.

Data Specification & Generation

Training Requirements

The model requires high diversity in lighting (dawn, dusk, noon), weather (clear, overcast), and debris types to generalize well.

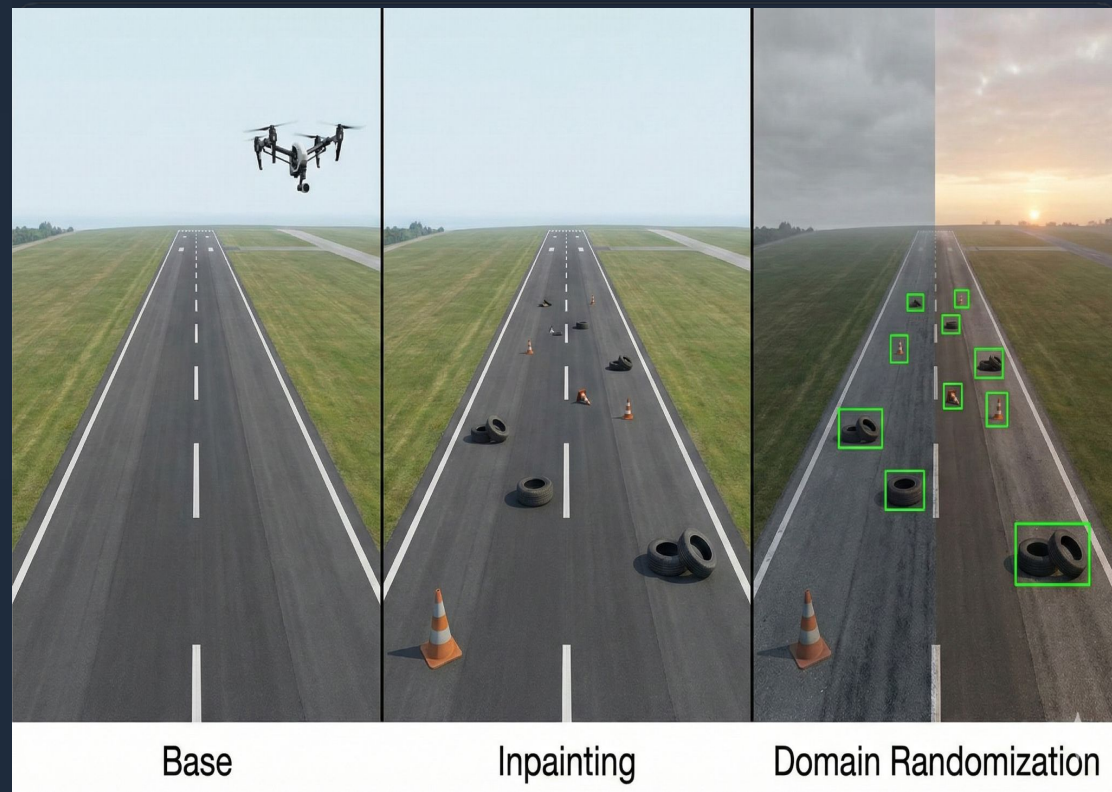
Synthetic Data Strategy

We generate **10,000+ synthetic samples** using GenAI:

- **Base:** Clean runway textures from CCTV/drone data.
- **Inpainting:** Inserting hazards naturally with shadow consistency.
- **Domain Randomization:** varying textures and debris scale.

Labeling Protocol

Zero-manual effort. Bounding boxes are derived mathematically from the inpainting mask coordinates.



Metrics & Evaluation KPIs

Metric Category	Specific Protocol	Target KPI
Detection Accuracy	F1-Score, Confusion Matrix	> 85.0%
Localization	Center offset error	< 20 pixels
Synthetic Quality	FID (Fréchet Inception Distance)	< 30.0 (Photorealistic)
Processing Speed	FPS	30+ FPS (Real-time)
Safety Critical	Recall, High precision	> 90%