Can We Detect Failures Without Failure Data? Uncertainty-Aware Runtime Failure Detection for Imitation Learning Policies

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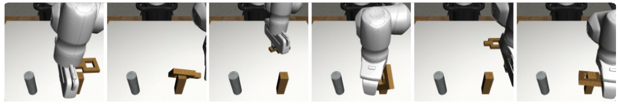
Motivation

Generative imitation learning policies are prone to failure:



Challenges :

- High-dimensional action and observation data.
- Demonstration data contain only successful trajectories.
- Diverse failure types occur during deployment.

Solution: A modular two-stage runtime failure detector

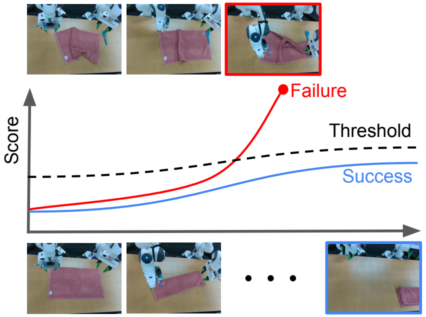
✔ Extracts **scalar scores** from high-dimensional data and uses conformal prediction to threshold when to alert failure.

✔ Requires **no failure** training data.

✔ Capable of detecting **different kinds of failures**.

Proposed Framework

- **Stage 1:** Extract scalar detection scores given data in each rollout.
- **Stage 2:** Determine detection threshold using conformal prediction band.



- **Sequentially** detect failures if scores exceed thresholds.
- Alarm is raised under **physical changes** in the environment.
- **Flexible** to:
  - Incorporating new scores and thresholding schema.
  - Building on *any* imitation learning policy.

Stage 1: Scalar Score Design

Desiderata:

1. **One-class**: No failure data is required.
2. **Light-weighted:** Fast inference for real-time robot control.
3. **Discriminative:** Gap in scores between successes/failures.

Based on **SOTA OOD detectors:**

(a) learned data density

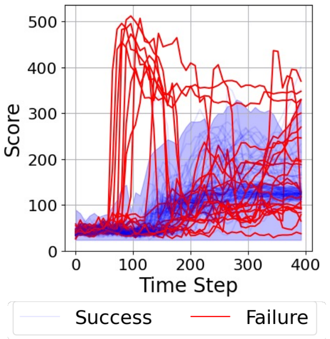
(b) second-order distribution

(c) one-class discriminator

(d) post-hoc metrics

Stage 2: Sequential Threshold

- Construct thresholds as a one-sided conformal prediction band.
- Threshold **adapt temporally** to score variations.
- **Theoretically controls** false positive rate.



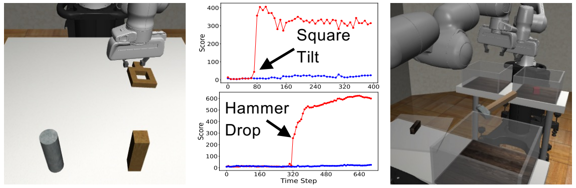
References

[1] *Christopher Agia et al.* **Unpacking Failure Modes of Generative Policies: Runtime Monitoring of Consistency and Progress. CoRL '24**

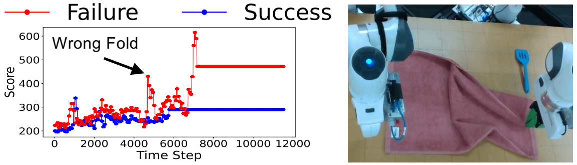
Experimental Results

Physically Meaningful Metric

Sudden rise in scores indicates failure has occurred.



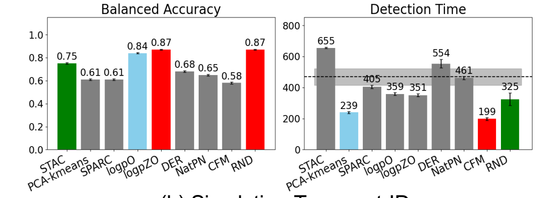
(a) Simulation-Robomimic



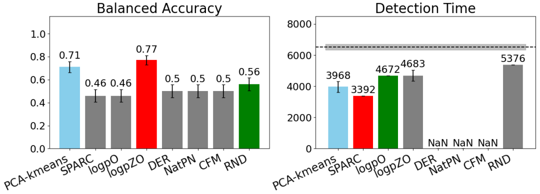
(b) On-Robot-OOD

Quantitative Comparison

- Top three: red > blue > green
- Our proposed *logpZO* performs best in Accuracy.
- No batch sampling: significantly faster than STAC [1].



(b) Simulation-Transport-ID



(b) On-Robot-OOD