Uncertainty-Aware Failure Detection for Imitation Learning Robot Policies

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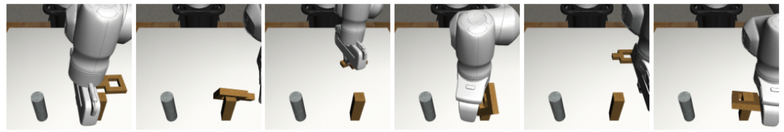
Motivation

Generative imitation learning policies are **prone to failure**:



Challenges:

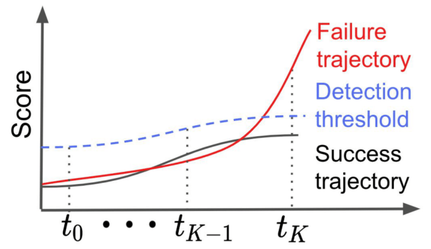
- High-dimensional action and observation data.
- Demonstration data contains only successful trajectories.
- Diverse failure types occur during deployment.

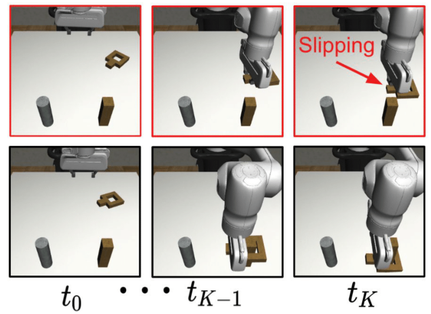
Solution: A modular two-stage runtime failure detector

- ✔ 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 when there are **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:

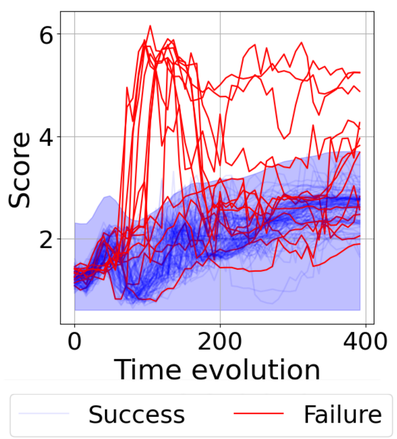
1. **One-class:** No failure data is required.
2. **Light-weight:** Fast inference for real-time robot control.
3. **Discriminative:** Gap in scores between successes/failures.

Built on **SOTA OOD detectors**:

(a) learned data density
(b) second-order distribution
(c) one-class discrinimator
(d) posthoc metrics.

Stage 2: Sequential Threshold

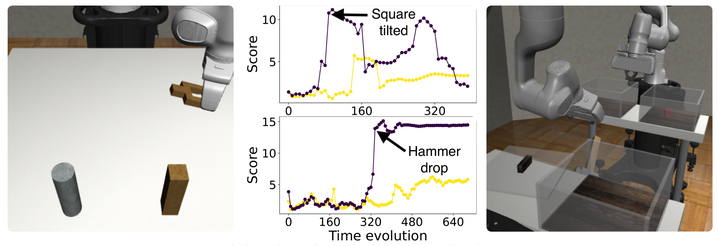
- Construct thresholds as a one-sided conformal prediction band.
- Thresholds **adapt temporally** to score variations.
- **Theoretically controls** false positive rate.



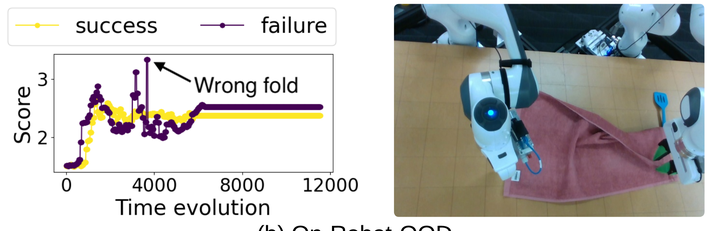
Experimental Results

Physically Meaningful Metric

Sudden rise in scores indicates failure has occurred.



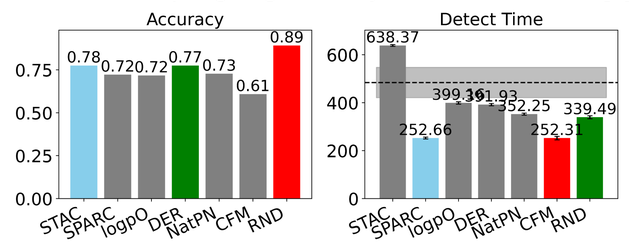
(a) Simulation-Robomimic



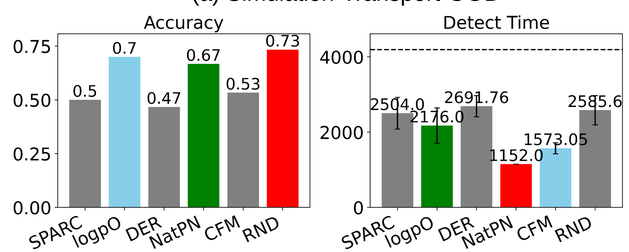
(b) On-Robot-OOD

Quantitative comparison

- Top three: red > blue > green
- RND [1] learned scores perform best in Accuracy.
- No batch sampling; significantly faster than STAC [2].



(a) Simulation-Transport-OOD



(b) On-Robot-OOD

References

[1] Nantian He et al. **ReDiffuser: Reliable Decision-Making Using a Diffuser with Confidence Estimation. ICML'24**
[2] Christopher Agia et al. **Unpacking Failure Modes of Generative Policies: Runtime Monitoring of Consistency and Progress. CoRL'24**