Modular Sim-to-Real Evaluation of Zero-Shot RL Policy Transfer: Toward Reproducible Field Testing of Perception and Control Integration

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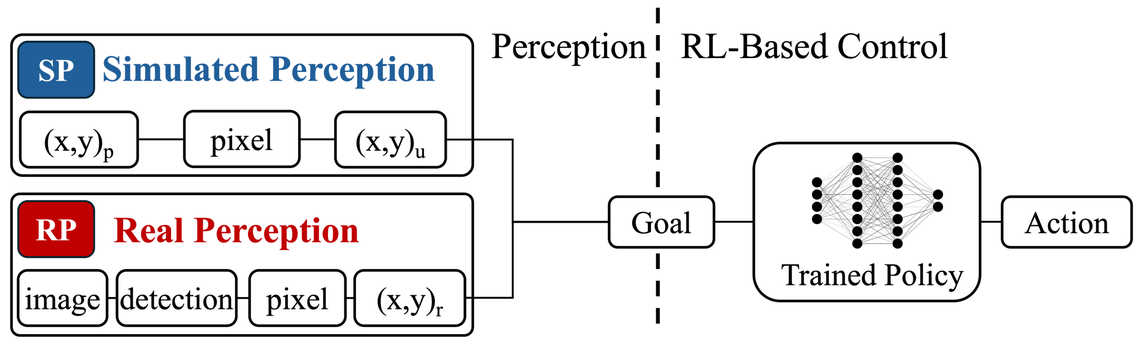
Summary

- **Task: Perception-driven RL point-goal navigation for floating waste capture with an ASV**
- **Problem: Evaluating sim-to-real transfer of RL-based control policies with real perception in the loop lacks repeatability**
- **Goal: Enable modular, reproducible evaluation of zero-shot RL policy transfer by decoupling perception from dynamics evaluation.**

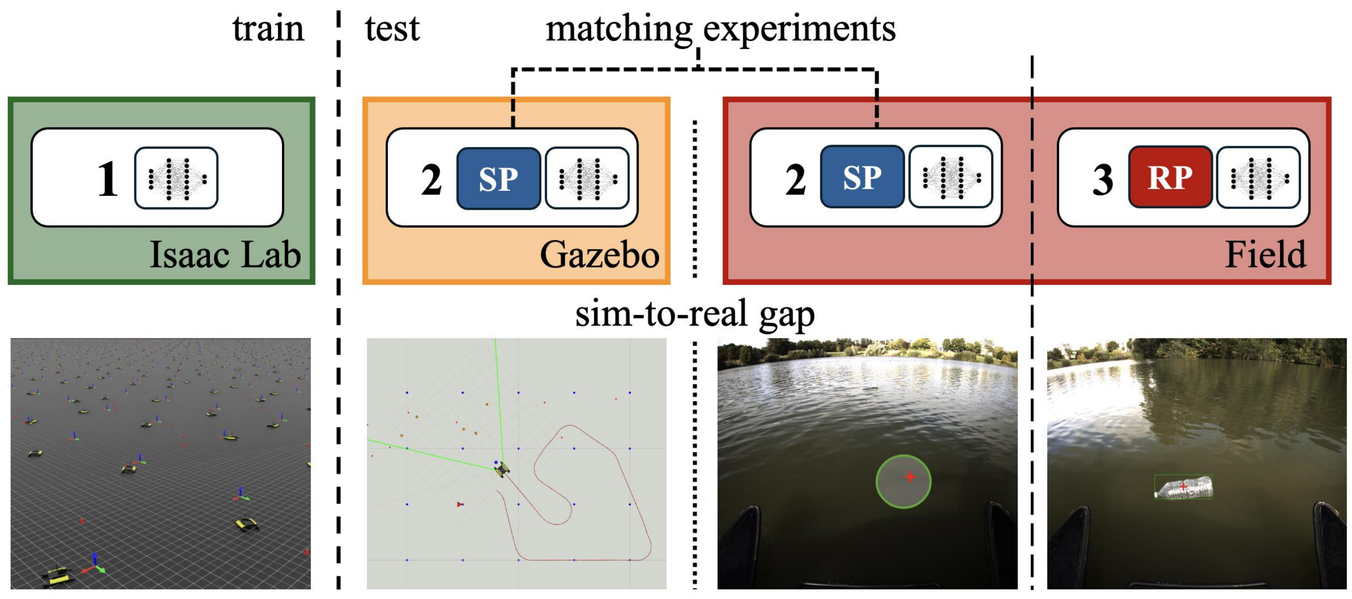
Simulated Perception Abstraction

A simulated perception module operates at the perception–control boundary, replacing camera-based detection with a calibrated projection model under controllable perturbations.

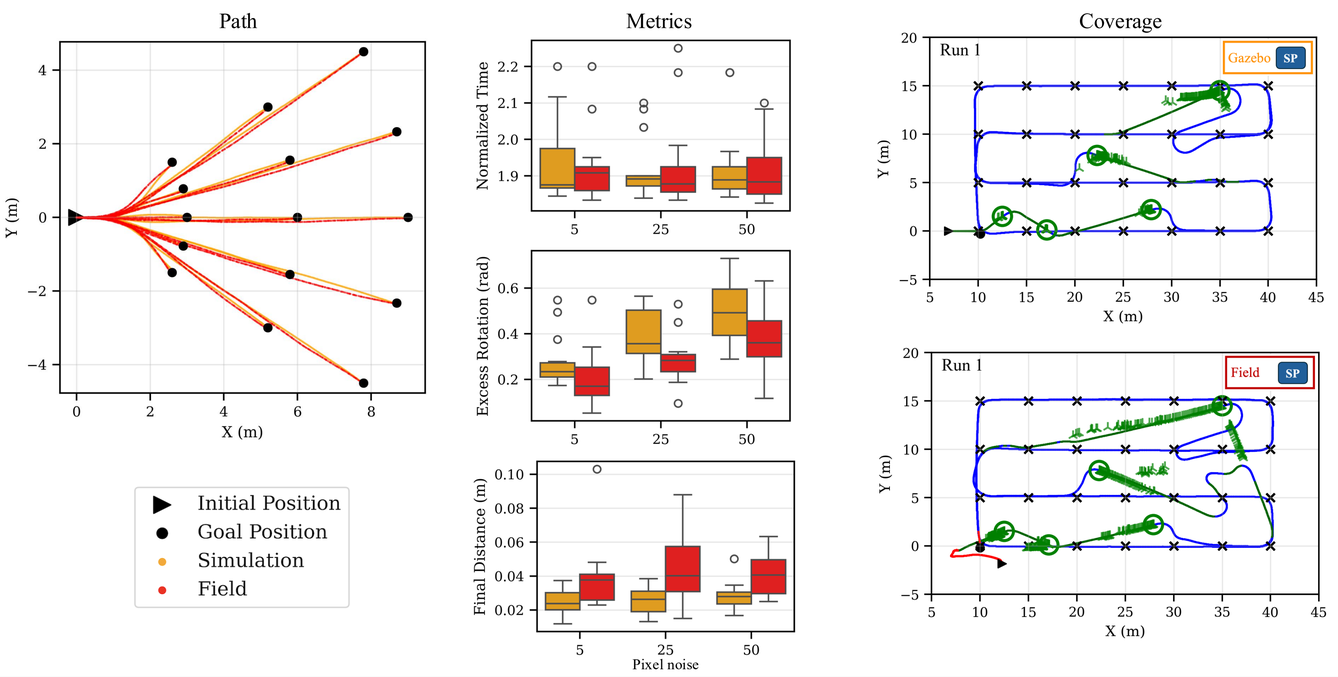


Methodology and Field Tests

Dual-sim methodology with perception abstraction capability



Systematic robustness evaluation and sim-to-real gap analysis



Field tests with perception in the loop

- **Smaller scale (area coverage)**

Number of runs: 5

Bottles: 40

Manual interventions: 5

Autonomous Time: 1h5m

Total distance: 2.0 Km

- **Larger scale (assisted operation)**

Total Distance: 2.5 Km **Total Time: 1h22m**

Simulated Perception Implementation

Plane induced homography $H = K\,[\mathbf{r}_1 \;\; \mathbf{r}_2 \;\; \hat{t_{cr}}]$

Image plane (pixel) $\tilde{\mathbf{x}}_u = [u\ v\ 1]^T$

Real world position (X, Y)

Transformations $\tilde{\mathbf{x}}_u \sim H \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} \quad \begin{bmatrix} X \\ Y \\ 1 \end{bmatrix} \sim H^{-1}\tilde{\mathbf{x}}_u$

Controllable perception disturbances:
Pixel noise radius, tilt angle, false negatives

Conclusion

The simulated perception abstraction provides a practical, modular methodology to isolate and quantify the impact of perception on zero-shot RL policy transfer, enabling systematic exploration of perception disturbance limits, precise attribution of sim-to-real gap sources, and targeted improvements toward reliable field deployment.