technische universität dortmund

Lehrstuhl für Förder- und Lagerwesen

Supervisory Localization for Multi-Robot Fleets

Motivation

Fleets of mobile robots in warehouses and factories typically require per-robot localization (LiDAR SLAM, VIO, beacon infrastructure), creating a cost barrier that scales linearly with fleet size. This thesis investigates a **supervisory alternative**: one privileged reference robot with full localization provides intermittent pose corrections to N observed robots that navigate using only wheel odometry. The reference agent perceives the fleet through onboard sensors and distributes observations according to a scheduling policy. The core trade-off is between correction frequency and fleet-wide position error as N grows.

Research Questions

1. **Drift Characterization:** How does odometry drift accumulate for differential-drive robots under realistic motion profiles?
2. **Scheduling and Scaling:** Which scheduling policy (round-robin, greedy uncertainty, drift-proportional) minimizes fleet-wide error, and how does performance scale with N?
3. **Sensor Comparison:** How do AprilTag-based visual detection and 2D LiDAR-based tracking compare as the perception link, in terms of pose accuracy, range, identification, and robustness?
4. **System Feasibility:** Can the architecture achieve bounded errors on 3–5 physical robots, and how closely do real-world results match simulation predictions?

Methodology

- **Phase 1 — Simulation:** 2D environment, $N = 2$ to 20, configurable narrow-FoV (camera-like) and wide-FoV (LiDAR-like) sensor models, three scheduling policies, EKF pose injection. Outputs empirical scaling curves and analytical bounds.
- **Phase 2 — Hardware:** Reference robot with LiDAR, camera, and AMCL localization; 3–5 observed robots with wheel encoders only. Characterize AprilTag detection and LiDAR-based robot tracking. Full ROS 2 supervisory pipeline.
- **Phase 3 — Evaluation:** Baseline drift test, scheduling comparison, $N = 3 \to 5$ scaling, head-to-head sensor comparison on identical trajectories, reference-agent failure and recovery test, sim-to-real gap analysis.

Expected Contributions

- Scheduling analysis with scaling laws for narrow-FoV and wide-FoV sensor regimes.
- Head-to-head evaluation of fiducial vs. LiDAR sensing for inter-robot detection.
- Working ROS 2 supervisory system validated on 3–5 physical robots with ground truth.
- Quantitative sim-to-real gap analysis and open-source simulation/ROS 2 release.

Out of scope

Formal observability and consistency theory, additional sensing modalities (sensors, learned detectors), dynamic role switching among multiple reference agents, outdoor environments, integration with planning layers. Physical fleet is limited to 3–5 robots; larger N covered in simulation only.