RFM-SLAM: Exploiting Relative Feature Measurements to Separate Orientation and Position Estimation in SLAM

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Introduction: Full SLAM

- Drive robot around environment
- Store sensor data (odometry, range-bearing etc.)
- Solve non-linear optimization problem
The Problem

Non-linear optimization-based SLAM solvers often get stuck in local minima

Culprit: Odometry-based guess to initialize optimizer can be arbitrarily bad
Example Problem: 2D Feature-based SLAM

Traditional approach may lead to non-robust estimates

Ground Truth

Odometry-based Initial Guess

GTSAM Estimate

Catastrophic Failure
The Solution: Separate Orientation Estimation

1. Compute relative orientation constraints between poses
2. Solve On-Manifold orientation optimization problem
3. Solve linear least squares problem for position estimates
Result: RFM-SLAM

RFM-SLAM avoids catastrophic failure

Ground Truth

Odometry

RFM-SLAM Estimate
Key Takeaway

Separate Orientation and Position Estimation for Robust SLAM Solutions
Method: Step 1

Relative Displacement from Robot to Feature

Relative Displacement from Feature to Feature

Robot

Features
Method: Step 2

Setup Relative orientation constraint from feature to feature measurements
Method: Step 3

Solve on-manifold optimization using MANOPT*

Method: Step 4

Solve linear least squares problem to compute robot and landmark position.

\[
\begin{align*}
  l_i - p_1 &= C_1^T l \Delta_1^i \\
  l_i - p_2 &= C_2^T l \Delta_2^i
\end{align*}
\]
Result: Increasing odometry noise

RMS Trajectory Estimation Error

α: Odometry noise scaling factor

β: Range-bearing noise scaling factor
Result: Increasing range-bearing noise noise

α: Odometry noise scaling factor

β: Range-bearing noise scaling factor
Summary

- Problem: Non-linear SLAM solver prone to local minima
- Solution: Decouple orientation from position
- Result:
  - Accuracy degrades gracefully as noise goes up
  - Empirical results show RFM-SLAM avoids catastrophic failure
- Impact: Use RFM-SLAM to bootstrap non-linear solvers
Relevant Related Work

Software

https://github.com/sauravag/edpl-rfmslam

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