Fully Distributed Multi-Robot Simultaneous Localization and Mapping

Alex Cunningham and Frank Dellaert
Center for Robotics and Intelligent Machines, Georgia Institute of Technology, Atlanta GA, 30332

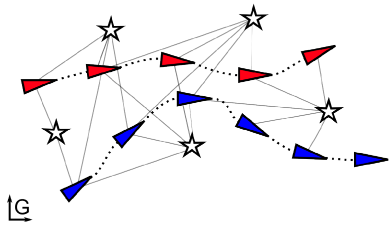

Figure 1. An example scenario with two robots driving through an environment with landmarks (stars).

Abstract

Multi-robot SLAM systems are necessary to coordinate teams of robots by producing consistent, reliable maps of the environment. One challenge in a multi-robot system not present in single robot SLAM is finding globally consistent labels for landmarks observed by separate robots when the starting reference frames of the robots are not known. We present a novel, RANSAC-based, approach for performing the between-robot data associations and initialization of relative frames of reference, obtaining an end-to-end multi-robot SLAM system, when combined with our previous DDF-SAM approach, for which have only shown simulated result until now.

Overview

The primary requirements for multi-robot mapping system useful in harsh environments, which performs Decentralized Data Fusion (DDF), are as follows:

- Scalable in computational cost
- Scalable in communication bandwidth as the number of robots increases
- Robust to node failure
- Robust to changes in network topology

DDF-SAM

The DDF-SAM system, introduced in [1] and expanded in [2], consists of three main modules:

1) **Local Mapping Module**: Performs full nonlinear SAM to solve for the full trajectory and landmark map, then compresses the local map to broadcast to neighboring robots.
2) **Communications Module**: Updates a cache of compressed maps from many robots with correspondences and initializations and computes multi-robot data associations.
3) **Global Mapping Module**: Optimizes graph over all known neighbors and yields a global feature map.

Local Smoothing and Mapping (SAM) solves nonlinear least-squares optimization problem, while global optimization introduces *hard equality constraints* to bind landmarks in different reference frames together.

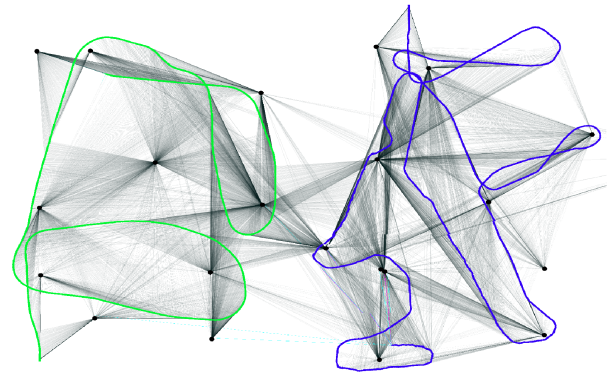

Figure 2. Two robots with globally consistent landmarks (black circles), showing corrected trajectories (green and blue lines) and landmark observations (translucent lines), shown after aligning landmarks and global optimization.

Map Matching

- Rather than matching landmarks directly, we compute features on the landmarks
- We compute *Delaunay triangulations* (shown in Fig. 3) over the landmarks in a map
- Correspondences between the triangles will be more robust to noise
- We use these triangle correspondences as inputs to a RANSAC algorithm to find data associations and relative reference frames

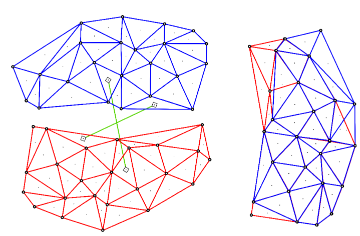

Figure 3. Map matching via triangulations of feature maps. Left: two sets of landmarks, their triangulations, and correspondences. Right: matched maps overlaid.

Experiments

We tested the system in the following scenario

- Three robots (shown in Fig. 4) equipped with laser scanners
- Parking lot environment with pole features added
- Two runs through the environment, manually controlled by human

All results were computed off-line for visualization, using the *GTSAM* graphical inference library for optimization. Full map outputs can be seen in Fig. 5, with a closeup of a two-robot case in Fig. 2.

Figure 4. Robots used for experiment and example pole feature (left) and aerial view of the parking lot used in Freiburg.

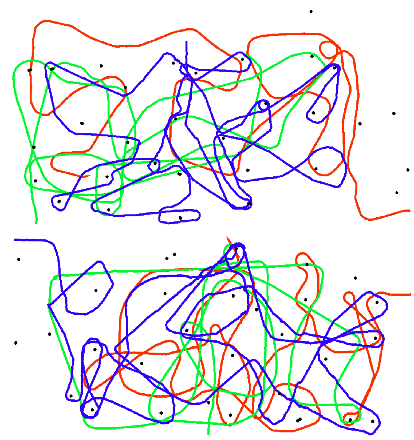

Figure 5. Full trajectories and global landmarks with 3 robots in Freiburg dataset for run 1 (top) and run 2.

Conclusions

- Decentralized multi-robot maps are feasible with real-time performance
- We can assemble a global map even when the initial positions of the robots are unknown
- The system scales with the number of robots while producing accurate maps, as in Fig. 2 and Fig. 5

Acknowledgements

Freiburg experiments and the data association approach come from joint work with Kai Wurm and Wolfram Burgard at the University of Freiburg.

References

[1] A. Cunningham, M. Paluri, and F. Dellaert, "DDF-SAM: Fully distributed SLAM using constrained factor graphs," in *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2010.

[2] A. Cunningham, K. Wurm, W. Burgard, and F. Dellaert, "Fully distributed smoothing and mapping with robust multi-robot data association," submitted to *IEEE/RSJ Intl. Conf. on Intelligent Robots and Systems (IROS)*, 2011.

Robotics@GT
& Intelligent Machines