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Distributed Visual Simultaneous Localization and Mapping



Computer Science Tripos – Part II
Queens' College

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Declaration

I, Joshua Bird of Queens' College, being a candidate for Part II of the Computer Science Tripos, hereby declare that this dissertation and the work described in it are my own work, unaided except as may be specified below, and that the dissertation does not contain material that has already been used to any substantial extent for a comparable purpose. In preparation of this dissertation I did not use text from AI-assisted platforms generating natural language answers to user queries, including but not limited to ChatGPT. I am content for my dissertation to be made available to the students and staff of the University.

Signed: Joshua Bird

Date: February 20, 2024

Proforma

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Original Aims of the Project

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Special Difficulties

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²This code line count was computed using `clloc` (excluding autogenerated test output).

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Chapter 1

Introduction

Visual Simultaneous Localization and Mapping (visual SLAM) serves as the foundation of countless modern technologies, with self driving cars, augmented reality devices and autonomous drones just being a few examples. By using purely visual inputs, visual SLAM is able to create a 3D map of the surroundings while also localizing the camera's position within this map in real time.

Unlike other SLAM systems which may use expensive and heavy sensor such as LIDAR, RGB-Depth cameras or Radar, visual SLAM only requires the ubiquitous camera sensor, allowing the technology to be used in many commercial applications such as Google's ARCore¹, Boston Dynamic's GraphNav system used on their robot Spot², and several models of DJI quadcopters³ making this a particularly practical field of research.

1.1 Relevant Work

While there have been many advanced implementations of visual SLAM over the last decade, very few of them have focused on distributed multi-agent systems, instead focusing on single-agent or centralized multi-agent systems. ORB-SLAM3 [1] is perhaps the most popular single-agent SLAM system, and often ranks at the top of benchmarks in a variety of environments [2], however it is fundamentally a single-agent system with no considerations in place for collaboration among peers. Out of the few multi-agent systems that do exist, the majority of them require a centralized server to manage communications between the agents and perform map merging, such as CCM-SLAM(2019) [3] and COVINS(2021) [4] among many others.

todo: add comparison table?

1.2 Motivation

Multi-robot systems are only becoming more common as automation in numerous fields continues to grow, such as self driving cars, drone swarms and warehouse robots. These systems require the agents to understand the world around them, as know each other's locations within that world for collision avoidance. This task is often achieved with technologies such as GPS or motion capture setups, however we can not assume that all environments will have access to these systems. A few emerging examples include:

¹<https://developers.google.com/ar/develop/fundamentals>

²<https://support.bostondynamics.com/s/article/GraphNav-Technical-Summary>

³DOI: 10.1016/j.vrih.2019.09.002

- Search and rescue operations in large indoor systems, assisted by drone swarms.
- Self driving cars in underground road networks.
- Multi-agent cave/subsea exploration.

These are scenarios where multi-agent SLAM is able to assist, as it enables us to build a map of an unknown environment and keep agents aware of their relative poses. However, as noted in section 1.1, the majority of existing multi-agent visual SLAM implementations are centralized systems, requiring the agents to maintain reliable communications with the central server in order to operate. This is somewhat counterintuitive, as environments which don't have access to GPS or motion capture systems are more than likely to also have very poor communication channels – greatly limiting the use cases of these centralized multi-agent SLAM systems.

Naturally, this leaves us with distributed multi-agent visual SLAM systems which do not rely on a centralized management server, allowing the agents to be used in environments where network infrastructure may be lacking. Instead of a central node, the agents are able to communicate peer-to-peer when they come within close proximity with one another.

It is easy to see the broad reaching uses cases this opens up. Agents will be able to explore sections of the world independently or in small teams, sharing new world locations with their peers as they come into communication range using an ad-hoc network. Agents will only know their peer's locations when they are within communication range, but this is sufficient if we only need the relative position for collision avoidance (as is common in multi-robot systems).

My project implements a distributed multi-agent visual SLAM system, where agents are able to share information with each other to enable more accurate localization, relative positioning, and collaborative map building.

1.3 Project Overview

In this project, I:

1. Design and implement a distributed multi-agent visual SLAM system that is capable of localization, relative pose estimation and collaborative mapping, all while being tolerant to degraded network conditions and not reliant on any one single leader agent.
2. Create a simulation environment for testing and evaluating my system locally.
3. Evaluate the performance of my system on standardized datasets, comparing its performance to other visual SLAM systems.
4. TODO: Deploy my system on physical robots, demonstrating the practical use cases of this system and benchmarking real world performance.
5. TODO: Map compression algorithms?

Chapter 2

Preparation

2.1 Starting Point

2.2 Requirements Analysis

Preparation Section 1...

Chapter 3

Implementation

Implementation...

3.1 Implementation Section 1

Implementation Section 1...

Chapter 4

Evaluation

Evaluation...

4.1 Evaluation Section 1

Evaluation Section 1...

Chapter 5

Conclusions

Conclusions...

5.1 Conclusions Section 1

Conclusions Section 1...

Bibliography

- [1] Carlos Campos et al. “ORB-SLAM3: An Accurate Open-Source Library for Visual, Visual-Inertial and Multi-Map SLAM”. In: *IEEE Transactions on Robotics* 37.6 (2021), pp. 1874–1890.
- [2] Dinar Sharafutdinov et al. “Comparison of modern open-source visual SLAM approaches”. In: *CoRR* abs/2108.01654 (2021). arXiv: 2108.01654. URL: <https://arxiv.org/abs/2108.01654>.
- [3] Patrik Schmuck and Margarita Chli. “CCM-SLAM: Robust and efficient centralized collaborative monocular simultaneous localization and mapping for robotic teams”. In: *Journal of Field Robotics* 36.4 (2019), pp. 763–781.
- [4] Patrik Schmuck et al. *COVINS: Visual-Inertial SLAM for Centralized Collaboration*. 2021. arXiv: 2108.05756 [cs.R0].

Appendix A

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Appendix A...

Appendix B

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Appendix B...

Appendix C

Proposal

Proposal...