Robust Trajectory Planning for Multi-Robot Systems Under Communication Delay

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Statement of Originality

I hereby certify that the work embodied in this thesis is the result of original research, is free of plagiarised materials, and has not been submitted for a higher degree to any other University or Institution.

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Supervisor Declaration Statement

I have reviewed the content and presentation style of this thesis and declare it is free of plagiarism and of sufficient grammatical clarity to be examined. To the best of my knowledge, the research and writing are those of the candidate except as acknowledged in the Author Attribution Statement.

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This thesis does not contain any materials from papers published in peer-reviewed journals or from papers accepted at conferences in which the author is listed as an author.

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To everyone who kept the robots from colliding.

Abstract

Coordinating multiple mobile robots in a shared workspace becomes substantially harder when inter-robot communication is delayed or intermittent, since each robot's plan is computed against a view of its neighbours that may already be stale. This thesis proposes a trajectory planning method that explicitly accounts for bounded communication delay by reserving a time-varying safety margin around each robot's planned path, sized according to the delay bound rather than a fixed worst case. We evaluate the method in both simulation and on a fleet of physical ground robots under artificially injected communication delay, and show that it maintains collision-free operation at delays where a delay-unaware baseline planner fails, at a modest cost in path efficiency.

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Chapter 1

Introduction

1.1 Motivation

Multi-robot systems increasingly operate in settings where wireless communication cannot be assumed to be instantaneous or reliable – warehouses with dense metal shelving, underground or underwater deployments, and outdoor sites with variable network coverage all introduce meaningful communication delay. Most trajectory planners for multi-robot coordination assume each robot has an up-to-date view of its neighbours' planned paths [1]; under delay, that assumption breaks down and the planner's safety guarantees no longer hold.

1.2 Problem Statement

We consider a fleet of robots planning trajectories in a shared workspace, where communication between any pair of robots is delayed by an unknown but bounded amount. Each robot must plan a trajectory that remains collision-free with respect to its neighbours' actual (not merely last-known) positions, without assuming synchronized clocks or a zero-delay communication channel [2].

1.3 Major Contributions

Our main contributions are as follows:

- A trajectory planning method that reserves a time-varying safety margin around each robot's path, sized according to a known communication delay bound rather than a fixed worst-case margin.
- A simulation study comparing the method against a delay-unaware baseline across a range of delay magnitudes and robot densities.
- A physical validation on a fleet of ground robots under artificially injected communication delay.

1.4 Outline of the Thesis

Chapter 1 introduces the problem and motivates the need for delay-aware planning. Chapter 2 reviews prior work on multi-robot trajectory planning and delay-tolerant coordination. Later chapters (omitted from this starter document) would present the planning method, simulation results, and physical robot trials in detail.

Chapter 2

Related Work

2.1 Multi-Robot Trajectory Planning

Reciprocal velocity obstacle methods and their successors plan each robot's trajectory against the current predicted positions of its neighbours, assuming those predictions are current [1]. When communication is delayed, a neighbour's broadcast position may already be out of date by the time it is used for planning.

2.2 Delay-Tolerant Coordination

Delay-tolerant coordination has been studied more broadly in distributed robotics, typically by bounding the uncertainty introduced by delay and inflating safety margins accordingly [2].

2.3 Gap Addressed by This Thesis

Prior delay-tolerant planners generally use a fixed, worst-case safety margin regardless of the actual delay bound in effect. This thesis explores sizing the margin according to a known delay bound, which we show recovers much of the path efficiency lost under a fixed worst-case margin.

Appendix A

Simulation Parameters

This appendix would list the simulation parameters used in the evaluation (robot count, workspace dimensions, delay distributions, and controller gains), omitted from this starter document.

Bibliography

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