Coordinated multi-robot motion planning: An overview

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Preface

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1 Introduction

1.1 General Overview

Robotic motion planning is a field of research in theoretical computer science which has been deeply studied. It focuses on designing and studying algorithms for making robots get from one point to another safely (without colliding) and efficiently (depending on the situation, minimizing time, resource usage or similar metrics) [1].

Robots are modeled in a vast variety of ways, which differ in terms of shapes, sizes and kinematics: some warehouse robots can be modeled to move in two dimensions only, while flying drones can be seen as moving in three dimensions.

Robotic arms that move an end-effector are often modeled in six dimensions: three spatial ones and three for orientation. These often have some so-called kinematic redundancy, meaning they have more degrees of freedom than strictly necessary. This means that the arm is able to re-adjust while holding the same end-effector pose, which helps dexterity and fault-tolerance, but also increases complexity in planning, as poses can have different alternative joint configurations. [2]

There are many different environments in which robots exist. Assembly line robots have a fairly static environment, well defined start and end positions, and a clear and safe path between them. Robotic vacuum cleaners on the other hand need to map their environment and make decisions dynamically, as furniture, people and pets can change places from time to time. Some robots need to work together; multi-robot systems can be found in warehouses [2], where parallel motion is highly desirable, but past research has focused mostly on algorithms moving robots one-by-one [3].

The many real world scenarios to be studied led to the formulation of different problems. The one we investigate in this thesis is *coordinated multi-robot motion planning:* making robots move effectively without colliding with other moving robots. The goal is to move the robots from a starting configuration to a target configuration,

The problem has multiple variations: In an unlabeled case, we do not care which robot gets to which target position, only that all target positions get occupied. Otherwise we have a labeled problem, where robots and target positions each have labels, such that target positions contain a robot with the same label at the end. Note that the labels can be unique or not, and some sources distinguish between these cases: for example, [3] uses *unlabeled, colored* and *labeled* as variations on the problem, such that labeled signifies unique labels.

The problem can also be modeled as continuous or discrete. The discrete variant is often handled using graph theory, while simple shapes like unit radius disks (see [3], [4]) or unit squares (see [5]) are often used in the continuous case.

Finding the minimum *makespan* solution to a discrete grid case of the problem is found to be NP-hard by [3]. NP-hardness implies approximation algorithms are justified [3], so research is focused on better approximations and faster computation.

1.2 Thesis Objective

The field of coordinated motion planning for parallel robotics has seen a lot of research in recent years, with different algorithms tackling different problems in the field. The scope is broad and the problems are varied but related. The goal will be to understand and explain current research in the field, what has been done and what is yet to be understood.

One of the key objectives will be to compare different algorithms in terms of their performance in computation and execution, strengths, weaknesses and scalability. How many robots can we support in a real system before motion planning becomes too slow?

1.3 Getting in depth

TODO start explaining a bit more in details these topics (definitions, results, difficulties)

There are two different types of motion problems: finding a collision free path from a starting configuration to a target configuration is called a *motion planning problem*, while determining if such a path exists is called the *mover's problem*. [6]

configuration space, joint space, holonomic, obstacles, PSPACE, polynomial time in terms of what?,

This thesis will focus on research on the motion planning problem,

A core term is a *configuration* and *configuration space*. A configuration of a system can be modeled as a vector of all the parameters specifying the state of the system. In It lies in the configuration space of the system. In essence, the motion planning problem is all about finding a valid path between two distinct points in the configuration space.

In a real world application it might be

1.3.1 Discrete Grid case

1.3.2 Continuous case

1.4 Considerations

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