Resolution-Complete Multi-agent Motion Planning with Arbitrarily-Shaped Obstacles

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***Abstract*—We present a novel algorithm for homogeneous multi-agent motion planning in a continuous workspace with arbitrarily-shaped obstacles. Our approach extracts the medial-axis of the workspace and takes advantage of its geometric characteristics to spatially divide the agents into multiple clusters. For each cluster, we arrange the agents into a circular pattern and compute their movements using a combination of inter-loop and intra-loop movements. In practice, we approximate the medial-axis and using a finite number of boundary samples to show that our planning algorithm is resolution-complete. We highlight its performance on challenging 2D benchmarks and highlight the benefits over prior methods.**

***Index Terms*—Multi-agent, resolution-complete, Arbirarily-Shaped, Medial-Axis.**

I. Introduction

MULTI-AGENT motion planning has been studied extensively in artificial intelligence, robotics and computer games. The objective is to navigate multiple agents from a set of start positions to corresponding goal positions while avoiding inter-agent collisions as well as collisions with obstacles. At a broad level, prior approaches can be classified into two categories: decentralized and centralized methods. For decentralized algorithms, the planner computes the trajectory for each agent separately for a short time horizon and uses some sort of coordination to avoid intersection between these local trajectories. On the other hand, the centralized methods combine the configuration degrees of each agent into one large high DOF (degree-of-freedom) system, which computes their paths together. Such centralized methods can provide completeness, including resolution-completeness or probabilistic-completeness guarantees. However, they are practical for scenarios with only a few low DOF agents.

II. Prior Work

The multi-agent path planning problem has been extensively studied in different areas. We give a brief overview of prior work in this area.

A. Decentralized Methods

In this approach, each agent moves independently and the method computes a collision-free trajectory for a short time horizon. These techniques are commonly used in games, crowd simulation, and robotics. Some of the widely used methods are based on social forces [1], rule-based methods [2], or geometric optimization [3], [4], etc. However, there are no guarantees that these methods can find a collision-free solution, if one exists. Moreover, the agents can get stuck in deadlocks, though many techniques have been proposed to overcome these problems [5], [6].

Another class of methods is based on decoupled algorithms. These techniques first calculate the agents' trajectories without considering each other as obstacles and then schedule their trajectories such that the agents avoid each other [7], [8], [9], [10]. These algorithms can handle a continuous workspace, but cannot provide completeness guarantees. Other decoupled algorithms [11], [12], [13] use different kind of movements when agents get close to each other. These are mostly limited to discrete workspaces.

B. Centralized Methods

These methods theoretically treat all of the agents' configurations as one unified high-DOF system and compute the collision-free paths for them. Different methods to compute the paths have been proposed. These include traditional searching [14], [15], [16], [17] and probabilistic path planning [18], [19], [20]. In practice, since these methods compute the paths for all agents at once, so they are limited to a few agents.

Another category of centralized methods is based on geometric decomposition techniques. [21], [22], [23] divide the workspace into several sub-areas, and agents move from one to another until they reach their goals. These algorithms control the agents' movements so that they avoid each other when they are in close proximity. While these algorithms work in a continuous workspace, the boundaries of this workspace are limited to polygonal shapes and the complexity of the algorithms increases as a function of the number of obstacle edges. [24] present an optimal algorithm, but the complexity is $O(n^2m^2)$, where n and m are the number of agents and the number of obstacles' edges, respectively. In their benchmarks, the algorithm [24] takes hundreds or thousands of seconds to calculate a solution. Our approach is also a geometric decomposition method. We can handle arbitrarily-shaped obstacles and exhibit up to 100X speedup over [24].

III. Limitations and Future Work

We present a novel method to compute collision-free paths for the homogeneous multi-agent motion planning with arbitrarily-shaped obstacles. We use the medial-axis of the workspace and our approach is resolution-complete. To the best of our knowledge, this is the first approach that can provide such guarantees for arbitrarily-shaped obstacles and we observe up to 100X speedup over prior methods. Our approach has some limitations. It is limited to homogeneous disc-like agents and does not take into account dynamics constraints. Furthermore, we can't provide any optimality guarantees. There are many avenues for future work. In addition to overcoming these limitations, we would like to design new methods based on medial-axis to simulate human-like behaviors or planning for high-DOF agents. Instead of moving one agent at a time, we would like to develop approaches that allow multiple agents to move simultaneously in complex scenarios.

APPENDIX A
PROOF OF THE FIRST ZONKLAR EQUATION

Appendix one text goes here.

APPENDIX B

Appendix two text goes here.

APPENDIX C
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