Jungwon Park

Research Statement

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Summary

My research focuses on multi-agent trajectory planning (MATP) for distributed robot systems. Distributed robot systems have received considerable attention in the industrial field since they can enhance efficiency and productivity through task division among multiple robots. However, as the number of robots increases, the computation time and risk of failures (e.g., collisions and deadlocks) also escalate. This raises a need for a fast and reliable MATP algorithm. **In my research, I seek to develop a scalable MATP algorithm that guarantees both safety and completeness, especially in obstacle-dense environments.**

During my doctoral work under the guidance of H. Jin Kim, I have focused on extending a MATP algorithm to be applicable in more challenging environments while ensuring important theoretical properties. As a result, I have made substantial progress in developing a MATP algorithm for a quadrotor swarm that encompasses the following key features: (i) collision avoidance, (ii) high scalability enough for online replanning, and (iii) deadlock resolution. In one of my recent works, I validated the safety and robustness of the proposed algorithm through a hardware demonstration in a maze-like environment with two pedestrians, as shown in Fig. 1.

Ultimately, my future research aims to further extend the MATP algorithm to provide generalized solutions for various applications and improve the state of the art in robotics and related fields. First, I intend to develop a decentralized MATP algorithm that ensures the agent reach the goal within a finite time in obstacle environments. Second, I plan to implement a scalable and robust MATP algorithm to deal with the complex challenges that may arise in the physical world, such as state estimation errors or robot communication failures. Third, I will extend the MATP algorithm for practical applications such as transportation, warehouse inspection, target chasing, and search and rescue.

(a) $t = 66$ s **(b)** $t = 68$ s **(c)** $t = 70$ s

Figure 1: Snapshots of the experiment with 10 quadrotors and 2 pedestrians in the maze-like environment [1].

Previous Research

Multi-robot systems, which include multiple mobile robots or unmanned aerial vehicles (UAVs), are widely used in applications such as transportation, surveillance, and search and rescue. Since a single accident in a multi-robot system can lead to the failure of the entire system, a safe and robust multi-agent trajectory planning (MATP) algorithm is essential. Among many MATP algorithms, decentralized approaches have been actively studied due to their high scalability and low computation load, which enables online planning. However, it has been challenging for the decentralized MATP algorithm to generate a safe trajectory in a cluttered dynamic environment. To tackle this, I have developed a scalable MATP algorithm that guarantees collision avoidance in obstacle-dense environments. Fig. 2 summarizes my previous research, and the following subsections will present the key features of each work.

Method	Centralized		Decentralized			
	IROS 2019 [2]	ICRA 2020 [3]	RA-L 2021 [7]	RA-L 2022 [4]	T-RO 2023 [1]	ICRA 2023 [8]
Inter-agent collision avoidance	**Yes**	**Yes**	**No**	**Yes**	**Yes**	**Yes**
Recursive feasibility	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
Consider dynamic obstacles?	**No**	**No**	**Yes**	**No**	**Yes**	**No**
Deadlock-free	**Yes**	**Yes**	**No**	**No**	**No**	**Yes**

Figure 2: Summary of the previous research.

A. Linear Safe Corridor

Since multiple robots share the same workspace, it is essential to use constraints that ensure collision avoidance between agents. However, if the collision constraints are too conservative, the MATP algorithm may generate inefficient trajectories. In addition, the collision constraints must be feasible to avoid optimization failure. To solve these problems, I proposed a new collision constraint construction method, Linear Safe Corridor (LSC) [2, 3, 4]. LSC guarantees inter-agent collision avoidance by exploiting the convex hull property of the Bernstein polynomial [5], as shown in Fig. 3. It is less conservative than Buffered Voronoi Cell (BVC) [6] because it can reflect the previous solution to the current optimization problem while BVC can only use the current position. Furthermore, I proved that LSC ensures recursive feasibility, which means that the proposed MATP algorithm always returns a safe trajectory without optimization failure. This work was nominated as a **finalist of Multi-Robot Systems Award** in ICRA 2020 [3].

B. Dynamic Obstacle Avoidance

For dynamic obstacle avoidance, many existing approaches assume that the future trajectory of the obstacles is given or the obstacles maintain a constant velocity. However, these assumptions are impractical in real-world scenarios. To address this issue, I extended the LSC approach to consider the reachable regions of dynamic obstacles [7], which enables robust obstacle avoidance without heavy computation. Furthermore, I introduced heuristics to prioritize obstacle avoidance when the agents encounter dynamic obstacles in a narrow space [1]. Through the hardware demonstration with two pedestrians (Fig. 1), I validated that the proposed algorithm can avoid

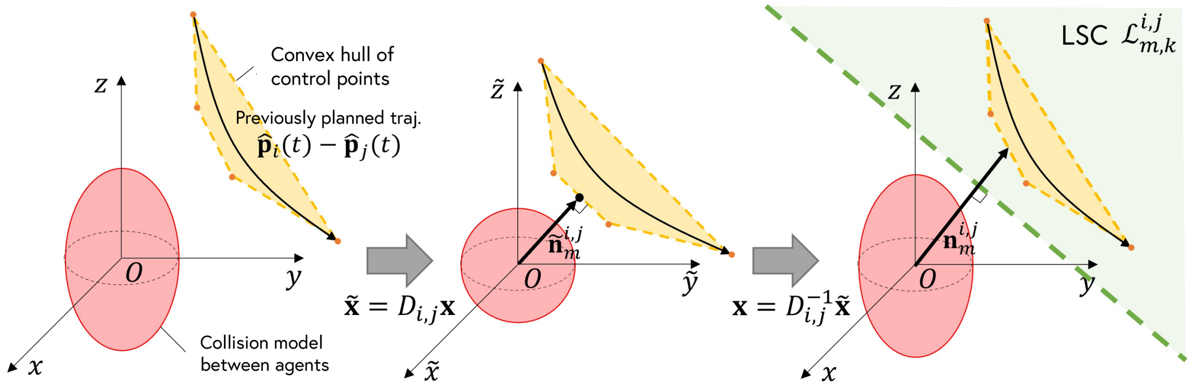

Figure 3: The construction process of Linear Safe Corridor.

dynamic obstacles in maze-like environments using only the position of the obstacles. This work was published in the **IEEE Transactions on Robotics (T-RO)**.

C. Deadlock Resolution

Due to the nature of decentralized approaches, deadlock resolution has been one of the significant challenges of decentralized MATP algorithms. To address this issue, I proposed a deadlock resolution method based on a subgoal optimization method [8]. The subgoal optimization allows the agent to converge to a waypoint without causing deadlock, and the waypoint can guide the agent to the desired goal because it is updated using the grid-based Multi-Agent Path Finding (MAPF) algorithm that ensures goal reachability [9]. To the best of my knowledge, it is the first decentralized MATP algorithm that guarantees no deadlock in obstacle environments. Furthermore, this work received the **top prize (President award)** in the **Korea Aerospace Industries (KAI) Paper Award**.

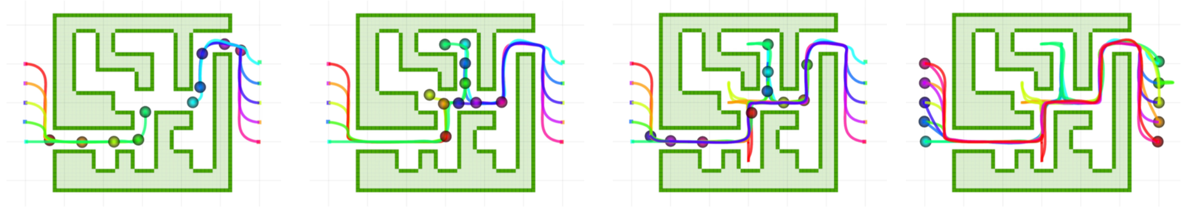

Figure 4: Deadlock resolution in the 2D dense maze [8].

D. Projects

In addition to my research, I have worked on various projects implementing path planning algorithms for autonomous vehicles, including quadrotors, cars, and ground robots. One notable project was developing a motion planning algorithm for autonomous driving vehicles in unstructured environments. In this project, I implemented the planning algorithm that can navigate challenging environments, including lane-less roads, dynamic obstacles (e.g., cars and pedestrians), and illegally parked vehicles. In another project, I implemented a path planning algorithm for mobile robots in a warehouse environment. The goal was to develop an online path planning algorithm that is scalable enough to handle over 100 robots. Despite this challenging condition, my algorithm could generate safe trajectories in less than 10 ms.

Future Directions

My future research aims further to advance the multi-agent trajectory planning (MATP) algorithms, providing generalized solutions for various applications and improving the state of the art in robotics and related fields. First, I'm working on developing a decentralized MATP algorithm that ensures *goal convergence*, which means that the agents can reach the desired goal within a finite time. While my previous work [8] successfully tackled the issue of deadlock, the risk of livelock still exists. To address this, I am actively testing candidate algorithms and working on theoretical proof. Second, I plan to improve the MATP algorithm for mobile robots in warehouse environments. In my previous project, I implemented a scalable MAPF algorithm for over 100 agents, but it was not robust enough to account for state estimation errors or network delays. For this reason, I will implement a robust MATP algorithm to handle complex challenges that may arise in the physical world. Third, I will extend the MATP algorithm for practical applications such as transportation, warehouse inspection, and search and rescue. I am particularly interested in exploring the efficiency of distributed robot systems in these applications and addressing hardware or network issues during implementation. I believe that my research will contribute to making robots more useful and practical in everyday environments.

References

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