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学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（工学）　氏名　RAVANKAR ABHIJEET

学 位 論 文 題 名

Novel Algorithms for Multi-Robot Path Planning, Task Coordination, Mapping and Localization in Indoor Environment
(室内環境におけるマルチロボット経路計画、タスク協調、環境地図構築及び自己位置同定のアルゴリズム開発)

Indoor mobile service robots face many different problems to perform tasks autonomously. These problems become more complex when multiple robots are deployed in the environment for different services. This thesis addresses the important problems faced by multiple autonomous mobile robots in indoor environments.

First, is the problem of smooth path generation for multiple mobile robots. A smooth and continuous path is desired for robot motion which avoids abrupt and sharp turns. This problem is further complicated in case of multiple robots which may have intersecting and common paths leading to deadlock conditions.

The second problem which frequently occurs in multi-robot scenarios is the problem of common resource sharing. Service robots for cleaning and patrolling are mostly in continuous operation and require frequent recharging. Using a large number of docking points proportional to the number of robots is costly and requires large space. A manager which can resolve conflicts and allocate the resource to the most appropriate robot by considering several factors is required.

Third, is the problem of autonomous map exploration and autonomous task distribution by multiple mobile service robots. Introducing multiple robots also introduce the problem of programming the robots to efficiently serve the region. The areas to serve vary with time. The number of the robots available to serve may also be dynamic. Explicitly programming the robots is cumbersome, and demands for a simpler scheme in which multiple robots can intelligently explore the map and distribute tasks.

The fourth problem is related to the third problem of exploration and task coordination using virtual pheromones which in most of the cases assumes pheromone deposition at perfect locations in the map. In reality however, it is difficult to achieve perfect localization of the robot due to errors in encoders and sensors attached to the robot. Failing to model this uncertainty would result in service robots depositing pheromones at wrong places. A leader robot may fail to localize causing follower robots to end up in wrong places.

The final problem is a fundamental problem of Simultaneous Localization and Mapping (SLAM) in autonomous mobile robots. In order to achieve efficiency in path planning, path smoothing, task distribution and other tasks, a robust SLAM algorithm is indispensable.

Solutions for each of the aforementioned described problems have been presented in the separate following Chapters:

Chapter 1:

This chapter presents an introduction to indoor service robots. It presents a brief introduction to the field of robotics and how mobile service robots are entering the day-to-day lives of people. The challenges faced by multiple service robots are presented along with the motivation of the work presented in this thesis.

Chapter 2:

This chapter discusses the state-of-the-art in the field of mobile service robots. Widely used techniques for path planning, path smoothing, robot perception, multi-robot cooperation and exploration algorithms are discussed in detail. The problems with the current techniques are also discussed which forms the base for the rest of the chapters.

Chapter 3:

This chapter presents a novel smooth hypocycloidal paths (SHP) for robot motion. It is integrated with collision-free and decoupled multi-robot path planning. SHP diffuses (moves points along segments) the points of sharp turns in the global path of the map into nodes which are used to generate smooth hypocycloid curves which maintain a safe clearance from the obstacles. These nodes are also

used as safe points of retreat to avoid collision with other robots. The novel contributions of this work are: (1) The proposed work is the first use of hypocycloid geometry to produce smooth and continuous paths for robot motion. A mathematical analysis of SHP generation in various scenarios is discussed. (2) The proposed work is also the first to consider the case of smooth and collision-free path generation for a load carrying robot. (3) Traditionally, path smoothing and collision avoidance have been addressed as separate problems. This work proposes an integrated and decoupled collision-free multi-robot path planning. 'Node caching' is proposed to improve efficiency. A decoupled approach with local communication enables dynamically changing the paths of robots without configuring the paths of all the robots. (4) A novel 'multi-robot map update' in case of dynamic obstacles in the map is proposed, in which, robots update other robots about the positions of dynamic obstacles in the map.

Chapter 4:

This chapter presents an intelligent docking station manager for multiple mobile service robots. The manager maintains a modified queue based on a score which is calculated from the task priority and the current power level of the robot. The behavior of the station manager in different scenarios when the docking station has empty docks and when it has none are discussed. The docking station can intelligently instruct a robot to forcefully relinquish a dock and give preference to the robots with higher task priorities and lower power levels. Emergency conditions for robots with power levels below threshold, and intelligent path allocation are also discussed.

Chapter 5:

This chapter presents a novel bio-inspired hybrid communication framework that incorporates the repelling behavior of anti-aphrodisiac pheromones and attractive behavior of pheromones for efficient map exploration of multiple mobile service robots. The proposed communication framework presents a scheme for robots to efficiently serve large areas of map, while cooperating with each other through proper pheromone deposition. This eliminates the need of explicitly programming each service robot to serve particular areas of the map. Experimental and simulation results are discussed with two cases of floor cleaning task, and surveillance task, performed by multiple robots.

Chapter 6:

This chapter presents a pheromone deposition algorithm which models the uncertainty of the robot's pose. Results from experiments in both simulated and real environments demonstrate that modeling the uncertainty in pheromone deposition is crucial, and that the proposed algorithm can model the uncertainty well. his modeling, as proposed in this chapter, provides extra information to the trailing robot about the preceding robot. A 'confident' deposition concentrated in a small area indicates that the preceding robot was certain about its location at that place. Whereas, low and dispersed pheromones indicate that the preceding robot was not sure about its location while depositing pheromones.

Chapter 7:

In all the previous chapters, it was assumed that multiple robots had a SLAM component. This chapter proposes an efficient algorithm for line detection from LRS data using a novel hopping-points Singular Value Decomposition (SVD) and Hough transform based algorithm, in which, SVD is applied on intermittent LRS points to accelerate the algorithm. A reverse-hop mechanism ensures that the end points of the line segments are accurately extracted. Line segments extracted from the proposed algorithm are used to form a map and subsequently LRS data points are matched with the line segments to localize the robot.

Chapter 8:

This chapter concludes the thesis with discussion on future works.