Chapter 17
A PSO-Inspired Multi-Robot Map Exploration Algorithm Using Frontier-Based Strategy

Yi Zhou
Shanghai Jiao Tong University, China

Kai Xiao
Shanghai Jiao Tong University, China

Yiheng Wang
Shanghai Jiao Tong University, China

Alei Liang
Shanghai Jiao Tong University, China

Aboul Ella Hassanien
Cairo University, Egypt

ABSTRACT

Map exploration is a fundamental problem in mobile robots. This paper presents a distributed algorithm that coordinates a team of autonomous mobile robots to explore an unknown environment. The proposed strategy is based on frontiers which are the regions on the boundary between open and unexplored space. With this strategy, robots are guided to move constantly to the nearest frontier to reduce the size of unknown region. Based on the Particle Swarm Optimization (PSO) model incorporated in the algorithm, robots are navigated towards remote frontier after exploring the local area. The exploration completes when there is no frontier cell in the environment. The experiments implemented on both simulated and real robot scenarios show that the proposed algorithm is capable of completing the exploration task. Compared to the conventional method of randomly selecting frontier, the proposed algorithm proves its efficiency by the decreased 60% exploration time at least. Additional experimental results show the decreased coverage time when the number of robots increases, which further suggests the validity, efficiency and scalability.

1. INTRODUCTION

Exploring unknown environment is a fundamental problem in mobile robotics. Yamauchi (1998) defines "exploration" as "Given what you know about the world, where should you move to gain as much new information as possible". Robots must know more information about their surroundings before performing complex tasks in a previously unknown environment. There are many applications of this scenario, such as: planetary exploration (Apostolopouslos, 2001), search (Qian, 2011), rescue (Murphy, 2004; Thrun, 2003; Baxter, 2002; Kantor, 2003), cleaning (Endres, 1998; Jäger, 2002), map building, hazardous material handling, military actions, etc. Compared to single robot system, multi-robot system receives better performance in reliability, robustness, efficiency and flexibility (Cao, 1997; Dudek, 1996). First, because of covering the environment in parallel, multi-robot system has the potential to complete exploration more quickly. Furthermore, the redundancy of robots provides robustness, since the breakdown of any robot does not severely degrade the performance of the system.

There are many factors affecting the overall performance of the multi-robot robot exploration process, such as robots moving to the same unexplored area, repeated coverage (a region visited more than once), the blockage and collision situation and the growth of communication when the number of robots increases.

Reynolds (1987) presents the model of Boids which simulates the flocking behavior of birds. Based on this idea, Kennedy and Eberhart (1995) proposed a novel population-based stochastic technique — Particle Swarm Optimization (PSO). PSO is widely used optimization algorithm in Swarm Intelligence (SI) research. Although it is an original application in the area of SI, swarm robotics still faces several challenging issues when using PSO algorithm. One of these issues is the difference between PSO and multi-robot task allocation optimization (Pugh, 2007). For example, the state of particles is called 'reaching an agreement' when all particles are on the same point in cognitive space. In multi-robot systems, when the robots and obstacles collide, they share the same position. As a result, it is necessary to design an avoidance algorithm. Furthermore, particles in PSO have a fitness value which is computed by the fitness function. In most situations, multi-robot task allocation optimization cannot provide the fitness function directly. Finally, in the real environment, robots are navigated to move, explore and sense in a more complex and unstable situation, compared to the abstract solution space in PSO algorithm. Therefore, it is required to find alternative solutions for applying the PSO model in this scenario.

To solve the above-mentioned problems, we propose a distributed map exploration algorithm using the modified PSO model. The map in the system consists of several subareas. Each robot explores the subarea of its own by moving to the frontier cells constantly. After completing the local subarea coverage, the robot turns into walking state which navigates robots to other unexplored subareas. In the walking state, robots decide its direction based on the PSO model which uses the local and global best information.

This paper is organized as follows: Section 2 introduces the related work. Then in section 3 the system of the proposed algorithm is described. After that, the proposed PSO-inspired algorithm is presented. Section 4 states the experiment in both simulation and real robots. Then section 5 analyzes the experimental results and concludes the paper. Section 6 is the acknowledgement.

2. RELATED WORK

Yamauchi (1998) proposed a distributed multi-robot exploration strategy. In this work, the concept of frontiers is introduced to designate the regions on the boundary between open and unexplored space. In

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