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Adaptive task assignment for multiple mobile robots via swarm intelligence approach☆

Dandan Zhang, Guangming Xie, Junzhi Yu, Long Wang*

Intelligent Control Laboratory, Department of Mechanics and Space Technologies, College of Engineering, Peking University, Beijing 100871, China

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Abstract

This paper describes an adaptive task assignment method for a team of fully distributed mobile robots with initially identical functionalities in unknown task environments. A hierarchical assignment architecture is established for each individual robot. In the higher hierarchy, we employ a simple self-reinforcement learning model inspired by the behavior of social insects to differentiate the initially identical robots into "specialists" of different task types, resulting in stable and flexible division of labor; on the other hand, in dealing with the cooperation problem of the robots engaged in the same type of task, Ant System algorithm is adopted to organize low-level task assignment. To avoid using a centralized component, a "local blackboard" communication mechanism is utilized for knowledge sharing. The proposed method allows the robot team members to adapt themselves to the unknown dynamic environments, respond flexibly to the environmental perturbations and robustly to the modifications in the team arising from mechanical failure. The effectiveness of the presented method is validated in two different task domains: a cooperative concurrent foraging task and a cooperative collection task.

Keywords: Task assignment; Learning; Swarm Intelligence

1. Introduction

In the field of cooperative robotics, task assignment is an issue receiving much attention [1–9]. In [1], a fully distributed, behavior based architecture is proposed, which facilitates fault tolerant cooperation of heterogeneous mobile robots. For cooperative transport task, Miyata et al. deals with a task assignment architecture for multiple mobile robots in unknown static environments [2]. A dynamic role assignment methodology modelled under a hybrid system framework is presented in [3]. To fulfill cooperative tasks in unknown dynamic environments, especially in desert places such as the Moon, Mars, or hazardous places, the robot team members are required to possess self-organizing capability to respond adaptively to the environments. An appropriate mechanism is required to assign the robot members among different tasks in an adaptive and flexible way. Inspiringly, the swarm intelligence approach is giving us ideas on dealing with this problem.

Derived from the behaviors of social insects, the swarm intelligence approach is exhibiting several good features, for example, self-organizing ability in unknown environments, emergent and adaptive behaviors through simple interaction among individuals, etc. Swarm intelligence based cooperation methods have been applied both to collective mobile robotics and multi-agent systems (MAS) [10–14]. Most of these methods discuss mainly one aspect of cooperation: some discuss cooperation problems among different task types, and others discuss cooperation problems among tasks of the same type. In complex task environments, a mechanism is required to not only allow parallel performing of different types of tasks, but also to allow efficient cooperation among robots engaged in the same type of tasks. This paper presents a novel mechanism dealing with both kinds of cooperation problems in one framework.

In social insect colonies, specialization is an appealing feature of some kinds of insects, through which the insect

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* Corresponding author. Fax: +86 10 62754388.
E-mail address: twinkleice@pku.edu.cn (D. Zhang).

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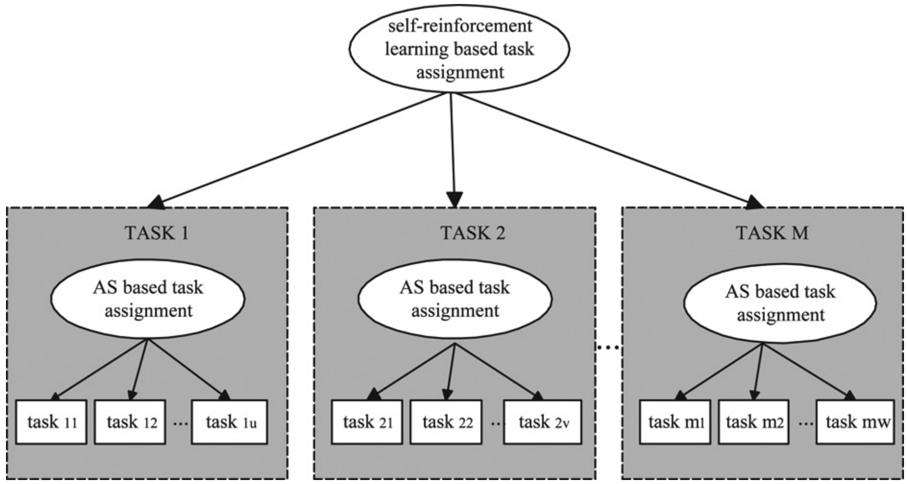

Fig. 1. Architecture of the relationship among tasks.

colonies allocate different tasks among individuals adaptively and flexibly, resulting in improvement of their fitness to the environments as well as increase of the resources they obtain. Thereby, specialization can be utilized in Multi-Robot Systems (MRS), leading the robots to adapt themselves to the unknown dynamic environments and fulfill their missions efficiently. In [10], a simple reinforcement learning mechanism for specialization is embedded in a behavior-based architecture for cooperating the members in MAS to perform a gathering task. In [13], Theraulaz et al. develops a specialization model based on the viable response thresholds to describe the labor division in some insect colonies where the thresholds are updated in a self-reinforcing way. In this paper, a mechanism developed based on this model is proposed for task assignment among different task types.

Without a priori knowledge about the environments, task assignment among tasks of the same type is another problem. Our proposed mechanism resorts to Ant System Algorithm (AS) [15] and employs the artificial pheromone as a clue for task difficulties. AS is an effective optimization method for solving discrete optimization problems in which the artificial pheromone is used as a clue for the ants to make decision. Similarly, in our mechanism, the robots select the different tasks of the same type with different probabilities according to the pheromone amounts and assign themselves in the performing of these tasks. Since the task difficulties are unknown to the robots, we are not aiming at finding optimal solutions for the task assignment, but sub-optimal solutions. A mechanism to avoid “task deadlock” (see Section 3 for details) is also proposed.

The proposed task assignment method is verified through simulations of two different task domains, a cooperative concurrent foraging task (CCFT) and a cooperative collection task (CCT). In CCFT, a group of mobile robots are required to explore and push several objects with different types to the destination cooperatively; while in CCT, the robots are required to explore and push several objects with the same type to the destination cooperatively. In both task domains, the difficulties of the objects are unknown to the robots. To accomplish the tasks effectively, a search strategy is also developed for the robots. Other example task domains that our mechanism is applicable for are also given.

This paper is organized as follows. In Section 2, the task description is given. In Section 3, the proposed task assignment method is described formally. Section 4 presents experiments of CCFT and CCT for demonstrating the task assignment mechanism. Simulation results are given in Section 5. Section 6 concludes the paper.

2. Task description

2.1. Task description

In this paper, the task assignment problem among a team of fully distributed, initially homogeneous mobile robots is studied. The robots have knowledge about neither the features of the environments nor the difficulties of the tasks. The tasks are categorized into different types and each type may include sub-tasks, that is, each type of task will be fulfilled through performing sub-tasks of that type. To improve efficiency, the task assignment mechanism allows allocating appropriate numbers of robots to different task types allowing the tasks to be performed in parallel, and dynamically reallocating the robots when the environment changes. We utilize a hierarchical model to describe the relationship among the tasks where different task assignment policies are applied in different task hierarchies. Fig. 1 presents the architecture of the relationship among the tasks. TASK 1, TASK 2, …, TASK M vary in types and they are high-level tasks, each contains low-level tasks respectively (TASK 1 contains task 11, task 12, …, task 1u, TASK 2 contains task 21, task 22, …, task 2v, TASK M contains task $M1$, task $M2$, …, task Mw). Difficulties of the low-level tasks are unknown to the robots and each low-level task needs to be performed by individual robot or multiple robots cooperatively.

2.2. Communication mechanism

Local blackboard communication mechanism is employed. In this mechanism, each robot member holds its own copy of