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Self-organizing techniques to improve the decentralized multi-task distribution in multi-robot systems

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ABSTRACT

This paper focuses on the general problem of coordinating multiple robots, in particular, addresses the problem of the distribution of heterogeneous multi-task in a robust and efficient manner. The main interest in these systems is to understand how from simple rules inspired by the division of labor in social insects, a group of robots can perform tasks in an organized and coordinated way. We take into account a specifically distributed or decentralized approach as we are particularly interested in experimenting with truly autonomous and decentralized techniques in which the robots themselves are responsible for choosing a particular task in an autonomous and individual way. Under this approach we can speak of multi-task selection instead of multi-task assignment, which means, that the agents or robots select the tasks instead of being assigned a task by a central controller. In this regard, we have established an experimental scenario to solve the corresponding multi-task distribution problem and we propose a solution using different approaches by applying the response threshold models inspired by division of labor in social insects, the application of the reinforcement learning algorithm based on learning automata theory and ant colony optimization-based deterministic algorithms. We have evaluated the robustness of the algorithms, perturbing the number of pending loads to simulate the robot's error in estimating the real number of pending tasks and also the dynamic generation of loads through time. The paper ends with a critical discussion of experimental results.

1. Introduction

Multi-Robots Systems (MRS) is one of the characteristic applied areas of Artificial Intelligence that has gotten an amazing growth since its inception until today [1,2], and it has developed very significant progress in various fields of application [3], becoming a fundamental tool to produce, work and perform dangerous jobs on earth and beyond. More specifically, within MRS, optimal task/job allocation or assignment is an active research problem [4], in which several central or global allocation methods have been proposed [5,6]. Some authors have also introduced decentralized or autonomous solutions, in particular inspired in the social labor division observed in some species of social insects [7,8].

This paper focuses on the general problem of coordinating multiple robots, in particular, addresses the problem of the distribution of heterogeneous multi-task in a robust and efficient manner. The main interest in these systems is to understand how from simple rules inspired by the division of labor in social insects, a group of robots can perform tasks in an organized and coordinated way. We take into account a specifically distributed or decentralized approach as we are particularly interested in experimenting with truly autonomous and decentralized techniques in which the robots themselves are responsible for choosing a particular task in an autonomous and individual way. Under this approach we can speak of *multi-task selection* instead of *multi-task assignment*, which means, that the agents or robots select the tasks instead of being assigned a task by a central controller.

In this regard, we have experimented with different techniques: firstly, the application of the response threshold models inspired by division of labor in social insects [9], secondly, the application of the reinforcement learning algorithm based on learning automata theory [10], and finally, ant colony optimization-based deterministic algorithms [11]. The key element in these algorithms is the estimation of the stimuli and the adaptive update of the thresholds. This means that each robot performs this estimate locally depending on the load or the number of pending tasks to be performed. The remainder of the paper is organized as follows: Section 2 presents the formal description of the general problem of decentralized distribution of multi-task/jobs in a multi-robot system, as well as a formal description of the experimental scenario. Section 3 briefly describes the response threshold models approach. Section 4 presents a brief introduction and

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basic definitions concerning the stochastic reinforcement learning algorithms based on learning automata theory. Section 5 describes a brief introduction of the ant colony optimization. Afterwards, in Section 6 we discuss the comparative experimental results obtained in applying both methods. The paper ends with the conclusions and some remarks on future work.

2. Formal definitions

2.1. Formal description of the problem

The optimal multi-task selection problem in multi-robot systems can be formally defined as follows:

- "Let $L=\{l_1(t), l_2(t), \ldots, l_J(t)\}$ be the different specialized tasks. Each $l_j \in L$ has a number of j jobs or pending loads where $J=\{j_1, j_2, \ldots, j_K\}$. Let $R=\{r_1, r_2, \ldots, r_N\}$ be the set of N heterogeneous mobile robots. We made several assumptions concerning the problem description mentioned above; we have supposed that all members $R=\{r_1, r_2, \ldots r_N\}$ are able to participate in any jobs or pending loads l_j".

Perform the multi-task selection in order to obtain an optimal distribution of a robot team formed by N heterogeneous robots with K different robot´s roles or robot´s jobs among the K different types of heterogeneous specialized tasks or equivalently, in such a way that the robots themselves, autonomously and in an individual manner, select a particular task such that all the existing tasks $L=\{l_1(t), l_2(t), \ldots, l_K(t)\}$ are optimally executed in the shortest time.

2.2. Application scenario

We have established the following experimental scenario (Fig. 1) in order to analyze a particular strategy or solution for the coordination of multi-robot systems as regards the optimal distribution of the existing tasks. Given a set of N heterogeneous mobile robots in a region, achieving an optimal distribution for different types of tasks. The set of N robots will form sub-teams for each type of task l_j. The sub-teams are dynamic over time, i.e. the same robots will not be always part of the same sub-team, but the components of each sub-team can vary depending on the situation.

Most of the proposed solutions in the technical literature are of a centralized nature, in the sense that an external controller is in charge of distributing the tasks among the robots by means of conventional optimization methods and based on global information about the system state [4]. However, we are mainly interested in truly decentralized solutions in which the robots themselves, autonomously and in an individual and local manner, select a particular task so that all the tasks are optimally distributed and executed. In this regard, we have experimented with response threshold models, stochastic reinforcement learning algorithms based on Learning Automata theory and ant colony optimization based on deterministic algorithms to tackle this hard self-coordination problem as described in the following sections.

3. Response threshold models

3.1. A brief introduction

The response threshold model assumes that individuals have inherent threshold to respond to stimuli associated with specific tasks and, in a group, the individuals with the lowest threshold for a task will perform this task more often. Division of labor emerges from the differences between individuals in their thresholds. Different versions of the response threshold model have looked at the effect of threshold reinforcement [12,13], colony size [14,15], number of tasks [16] and genetic diversity [17]. These studies assume that task stimuli are well-mixed in the environment; the cues used by individuals to choose tasks are therefore global.

Insect societies are characterized by the division of labor, communication between individuals and the ability to solve complex problems [18], and these characteristics have long been a source of inspiration and the subject of numerous studies, acquiring great relevance for many researchers both in the field of robotics as in biology. On one hand, the biologists are trying to prove their theories of social insects on robots, and on the other hand, researchers in the discipline of robotics seek solutions to problems that cannot be solved by a single robot.

Seeley et al. [19] have considered the following experiment to study the collective behavior in a colony of insects, focusing on the work performed by bees to get honey. Two food sources are presented to the colony at 8:00 A.M. at the same distance from the hive: source A is characterized by a sugar concentration of 1.0 mol/1 and source B by

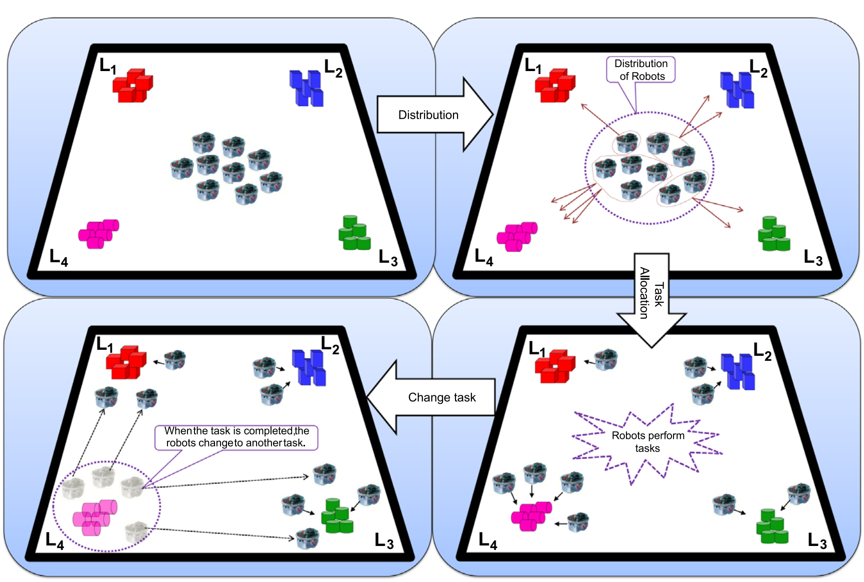

Fig. 1. Experimental scenario.