Università degli Studi di Verona

DIPARTIMENTO DI DI INFORMATICA
Corso di Laurea Magistrale in Ingegneria e Scienze Informatiche

Tesi di Laurea Magistrale

Multi-Robot Task Allocation for logistic applications

Candidato:
Davide Zorzi
Matricola vr414572

Relatore:
Alessandro Farinelli

Correlatore:
Riccardo Muradore

Anno Accademico 2017-2018

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Abstract

Robotics technology has recently matured sufficiently to deploy autonomous robotic systems for daily use in several applications: from disaster response to environmental monitoring and logistics. In this project present and evaluate the principal difference of central and distributed allocator task coordinator. In these applications we address off-line coordination, by casting the Multi-Robot logistics problem as a task assignment problem and proposing two solution techniques: Cyclic Greedy Strategy Single Robot Single Task (CGS1:1), which is a baseline greedy approach, and Cyclic Greedy Strategy Single Robot Multiple Task (CGS1:N), which is based on merging task for improve the spend time.
And the last one is address on-line coordiantor, that is based on token passing (TP) approach. We evaluate the performance of our system in a realistic simulation enviroment (build with ROS and stage). In particular, in the simulated enviroment we compare our task assignment approaches with previous off-line and on-line methods.

Keywords: Multi-Robot Task Allocator, logistic applications, Multi-Robot systems, coordination, task assignment

Chapter 1

Introduction

One of the fundamental areas in Robotics is multi-robot systems. More particularly, this thesis addresses the cooperation of a team of mobile robots in logistic missions. the main aspects studied herein are strategies for effective logistic performance, agent's coordination, scalability and applicability in real-life situations.
This introductory chapter presents the context of the research in order to clarify the motivation and significance of the problem. In addition, some guidelines about Multi-Robot systems in general and, more specifically, agents in logistic missions are herein introduced to lay the groundwork to approach the problem in hands. Finally, an overview of the document is given.

1.1 Context and Motivation

In recent years, robotics has been one of the scientific fields with the most substantial advances. Within the diverse areas that it embraces, mobile robotics has had great focus in the last decades from roboticists (i.e., researchers on robotics) around the world. In particular, issues like autonomous navigation, path planning, self-localization, coordination of robots, cooperative dynamics, mapping, exploration and coverage have become popular and have benefited from the progress of artificial intelligence, control theory, real-time systems, sensors' development, electronics, communication systems and systems integration [Parker, 2008].
Nowadays, we expect to see robots with many different shapes operating in different environments as on land, underwater, in the air, suspended on wires, climbing and so on. This evident growth is extremely motivating for the development and contribution of new developments by the community.
Security applications are a fundamental task with unquestionable impact on society. Combining this fact with the technological evolution observed in the last decades, it becomes clear that robot assistance can be a valuable resource by taking advantage of robots' expendability. In particular, multi-robot allocator task for logistic applications has high utility and is considered as a contemporary area with some relevant work presented in the last decade, especially in terms of strategies for coordinating teams of robots. However, many of the studies in the literature present unrealistic simplifications, strong limitations or questionable applicability as illustrated later on. Therefore, there is an eminent potential to explore in this context.
Moreover, the allocator task for logistic applications problem is very challenging in the

context of Multi-Robot systems, because agents must navigate autonomously, coordinate their actions in a distributed or centralized way and acquire information about the surrounding space, possibly with communication constraints and independently of the number of robots in the team and the enviroment's dimension. All of these features lead to an excellent case study in mobile robotics and conclusions drawn from such studies may support the development of future approaches not only in the logistic domain but also in multi-robot systems, in general.

1.2 Multi-Robot Systems

In many applications, an autonomous mobile robot equipped with different sensors may adequately complete a given assignment. However, in several situations, it proves to be more expensive, less efficient and less robust than using a multi-robot system. In some cases, due to the need of combining different tasks and the dynamics of the environment.

Some characteristics of multi-robot systems include distributed control, autonomy, communicative agents and greater fault-tolerance. A single robot may be vulnerable to hostile environments or attackers, for example, in military actions. In such scenarios, agents would greatly benefit from the assistance of nearby agents during emergencies, failures or malfunctions.

One of the main difficulties when approaching these systems is to coordinate many robots to perform a complex, global task in an efficient manner, maximizing group performance under a wide range of conditions, with the flexibility to take advantage of the resources available, embrace the requirements and constraints imposed and resolve issues like action selection, coherence, conflict resolution and communication. This cannot be done by just increasing the number of robots assigned to a task. A coordination mechanism must exist to establish relationships between agents so that they can accomplish the mission effectively.

1.3 The Multi-Robot system for logistic applications

Logistic apllication an infrastructure with multiple robots is no different than other multi-robot assignments, in the sense that it incorporates all the previously mentioned characteristics of Multi-Robot system. To understand this problem, it is important to firstly introduce the definition of logistic application.

Definition 1. *Industrial Logistics, the set of operations related to the procurement, destination and storage of materials and products of large industry; the coordination and provisioning of people or things for the purpose of higher production efficiency.*

Many real-world applications of Multi-Robot systems require agents to operate in known common environments. The agents are constantly engaged with new tasks and have to navigate between locations where the tasks need to be executed. On the other hand, the Multi-Robot system for logistic applications, given a set of agents attend to stream of incoming pickup-and-delivery tasks.

Chapter 2

Background and Related Works

In this section, we detail the main issues for Multi-Robot system coordination in industrial domains, then we provide a detailed discussion on coordination approaches, highlighting challenges and main solution techniques.

2.1 Multi-Robot system for Industrial Applications

In this thesis I also focus on industrial scenarios where robots have a high degree of autonomy and operate in a dynamic environment. In this work, I consider a similar setting where a set or robots are involved in trasportations tasks for logistics. However, I focus on the specific problem of task assignment ...

2.2 Coordination in Multi-Robot system

Coordination for Multi-Robot system (MRS) has been investigated from several diverse perspectives and nowadays, there is a wide range of techniques that can be used to orchestrate the actions and movements of robots operationg in the same enviroment. Specifically, the ability to effectively coordinate the actions of a MRS is a key requirement in several applications domains that range from disaster response to environmental monitoring, militaty operations, manufacturing and logistics. In all such domains, coordination has been addressed using various frameworks and techniques and there are several survery papers dedicated to categorize such different approaches and identifying most prominent issues when developing MRS.
Given my focus on logistic scenarios, here I restrict my attention to coordination approaches based on optimization and specifically on task assignment as this the most common framework for my reference application domain.

Chapter 3

Problem

In this section I detail my reference scenario for MRS coordination and formalization problem.

3.1 Description

My reference scenario is based on a warehouse that stores items of various types. Such items must bo composed together to satisfy orders that arrive based on customers' demand. The items of various types are stored in particular section of the building (*loading bay*) and must be trasported to a set of *unloading bays* where such items are then packed together by human operators. The set of items to be trasported and where they should go depends on the orders. In my domain a set of robots is responsible for for transporting items from the loading bays to the unloading bays and the system goal is to maximize the throughput of the orders, i.e., to maximize the number of orders completed in the unit of time. Now, robots involved in transportation tasks move around the warehouse and are likely to interfere when they move in close proximity, and this can become a major source of inefficiency (e.g., robots must slow down and they might even collide causing serious delays in the system). Hence, a crucial aspect to maintain highly efficient and safe operations is to minimize the possible spatial interferences between robots. Specifically, here we propose to take this interferences into account in the task assignment process and assign tasks to robots so to reduce the possible interferences among the transportation robots.

3.2 Fomalization

In this section I formalize the MRS coordination problem described above as a task allocation problem where the robots must be allocated to transportation tasks. In my formalization if transportation tasks are more than the available robots at each time step only a subset of tasks will be allocated. However, since the task allocation process is repeated over time robots effectively serve a sequence of tasks. In more detail, my model considers a set of items of different types $E = \{e_1, ..., e_N\}$, stored in a specific loading bay (L). The warehouse must serve a set of orders $O = \{o_1, ..., o_M\}$. Orders are processed in one of the unloading bays (U_i). Each order is defined by a vector od demand for each item type (the number of required items to close the order). Hence, $o_j =< d_{1,j}, ..., d_{N,j} >$, where $d_{i,j}$ is the demand for order j of items of type i. When an order is finished a new one arrives, and we assume to have no knowledge on future orders. The orders induce a set of $N \times M$ trasportation tasks $T = t_{i,j}$, with $t_{i,j} =< d_{i,j}, P_{i,j} >$, where $t_{i,j}$ defines the task of transporting $d_{i,j}$ items of type i for order o_j (hence to unloading bay U_j).

Chapter 4

Solution

Chapter 5

Experiments

Chapter 6

Conclusions

Acknowledgements