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MULTI ROBOT TASK ALLOCATION USING MARKET BASED APPROACH

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ABSTRACT

Multi robot task allocation (MRTA) can be defined as a set of robots working collaboratively in the same environment to achieve system goals by determining which robot should execute which task. Dangerous or hazardous environment which are not suitable for human being such as removing toxic waste, exploring planets, and removing landmines may require the use of robots. This project describes the algorithm design of multi robot task allocation problem in order to minimize mission cost in terms of time to reach a goal, distance travelled and energy consumption of all robots. This project presents a distributed market based approach, which solves the MRTA problems in applications that require the cooperation among the robots to accomplish the tasks. In market based approach, robots consider the cost function in the negotiation of subset of task via auction – bidder algorithm. The results obtained shows that the market based approach is able to minimize the distance travelled by robots but with some limitations. The system performance is analyzed and simulated using MATLAB software.

ABSTRAK

Pengagihan tugas robot boleh ditakrifkan sebagai sekumpulan robot yang bekerjasama dalam persekitaran yang sama untuk mencapai target sistem dengan menentukan robot mana yang perlu melaksanakan tugas yang diarahkan. Persekitaran berbahaya dan tercemar adalah tidak sesuai untuk manusia seperti tempat pembuangan sisa toksik, penerokaan planet, dan pembuangan periuk api yang mungkin memerlukan tenaga robot. Projek ini menerangkan penghasilan algoritma untuk pengagihan tugas robot yang bertujuan untuk mengurangkan kos dari segi tempoh masa untuk diperlukan untuk menamatkan tugas, jarak perjalanan dan penggunaan tenaga. Projek ini membentangkan pendekatan berasaskan pasaran (*market based)*, yang menyelesaikan masalah MRTA dalam aplikasi yang memerlukan kerjasama antara robot untuk menyiapkan tugas yang diberi. Dalam pendekatan berasaskan pasaran, robot mengambil kira kos dalam perundingan tugas melalui algoritma lelongan - pembidaan. Hasil eksperimen yang diperolehi menunjukkan bahawa pendekatan berasaskan pasaran mampu mengurangkan jarak yang dilalui oleh robot tetapi terdapat sedikit limitasi. Prestasi sistem telah dianalisis dan disimulasi menggunakan perisian MATLAB.

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LIST OF SYMBOLS OR ABBREVIATIONS

UAV	Unmanned Aerial Vehicles
UGV	Unmanned Ground Vehicles
UGV	Unmanned Underwater Vehicles
ISR	Intelligence, surveillance and reconnaissance
MRTA	Multi robot task allocation
MRS	Multi-robot systems
ST	Single-task robots
MT	Multi-task robots
SR	Single-robot tasks
MR	Multi-robot tasks
IA	Instantaneous assignment
TA	Time-extended assignment
MINISUM	Minimize the sum of the robot path costs over all robots.
MINIMAX	Minimize the maximum robot path costs over all robots
MINIAVE	Minimize the average target path costs over all targets
OPSP	One-Pair Shortest-Paths
SSSP	Single-Source Shortest-Paths
APSP	All-Pairs Shortest-Paths
RPC	Robot path cost
GUI	Graphical User Interface

CHAPTER 1

INTRODUCTION

1.1 Introduction

In late 1980’s, researchers started investigating the issues regarding multi robot system. As robots become an integral part of human life, people charge them with increasingly varied from simple task like house cleaning purpose up to difficult tasks including planetary exploration, manufacturing and construction, medical assistance, search and rescue in military field, port and warehouse automation. Works in challenging environment require robots to work collaboratively in teams rather than working alone [1].

Nowadays, the development of multiple mobile robot system has been moved to larger team size and greater heterogeneity of either robots or tasks. From centralized and homogeneous robot system, researchers began to investigate on decentralized and heterogeneous robot systems. Addition to task constraints, uncertainty and unforeseen changes, the complexity of the mission arises to optimise the robot technologies and enhance the problems faced [2].

Multi robot system mostly presented in three groups; Unmanned Aerial Vehicles (UAV), Unmanned Ground Vehicles (UGV) and Unmanned Underwater

Vehicles (UUV) as shown in Figures 1.1 – 1.3 below. All these UxVs commonly used for civilian and military missions. UAV has been used for civilian applications such as weather forecasting, environmental research, search and rescue missions, and observation during wildfire incidents and traffic control while for military domains, UAV has been approached for intelligence, surveillance and reconnaissance (ISR), security and air defence, search, attack, destroy and battle damage assessment [3] . In military domains, UGV primarily utilized for ordnance disposal, mine clearing operation, NBC decontamination and also as a goods transport, convoying and logistics [4].

Figure 1.1: UAV: RQ-1A Predator furnished with missiles.

Figure 1.2: UGV: CUTLASS used for explosive ordnance disposal (EOD) missions

Figure 1.3: UUV: REMUS 100 applications include mine countermeasure, harbour security and debris field mapping

The main issue in distributed multi robot coordination is the multi robot task allocation (MRTA) problem that has recently become a key research topic. Task allocation is the problem of mapping tasks to robots, such that the most suitable robot is selected to perform the most appropriate task, leading to all tasks being satisfactorily completed [5]. Ideally, in MRTA approaches, robots will act as a team to allocate resources amongst themselves in a way to accomplish their mission efficiently and reliably. The collaboration can lead to faster task completion, decreased the travelled distance and allow the completion of tasks which is impossible for single robots. Robots should, whenever possible, cooperate strongly in order to maximize their overall task performance.

Nevertheless, existence of obstacles may cause the collaboration among the robots become tougher, such as dynamic and uncertain environment, limited time to perform mission, and resource failures. Therefore, coordinating a multi robot team requires many research challenges to fulfil task assignment.

1.2 Problem Statement

For most of the missions, UAVs must traverse from their home base to the area of interest in order to accomplish the missions. In any mission, the cost of traversal is crucial and has to be taken into account as this will ensure that the UAVs will last longer and the maintenance cost is low [3]. The cost functions are measured in terms of time to reach a goal, distance travelled and energy consumption.

The mission cost can be reduced by minimising the travelling distance of UAVs in a mission. By reducing the distance, it is assumed that the energy consumption can also be optimised.

Hence, there is a need to formulate an algorithm that is capable of doing multi-robot task planning so that a mission can be accomplished in the shortest time possible, in which the traversal distance is optimal.

1.3 Aim and Objectives

The aim of this project is to design an algorithm to accomplish a task/mission by a team of UAVs (mobile robots) that work collaboratively. The mobile robots will share the prime target and able to visit several waypoints set in the system before reaching the prime target, but it must visit the nearest waypoint.

A number of objectives are set in order to achieve the target above and are structured as follows:

a) To find the shortest distance from initial point to the prime target in order to minimise the total path length and energy consumption.
b) To design an algorithm based on Market based approach using a programming language (MATLAB)
c) To analyse the system performance of the developed algorithm.

1.4 Scopes of Project

The scopes of this project are structured as follows:

a) The robots are not required to return to their starting positions.
b) Minimize the total distance of all robot paths, not individual path.
c) The mobile robot are not necessarily depart from the same depot
d) There will be no existence of unexpected obstacle.
e) The robots will not share the same waypoint, therefore no crash happen between the robots
f) The waypoints positions are generated randomly.
g) The number of waypoints visited by each robot is not restricted.

It is assumed that all robots are able to announce and bid for tasks. Every robot is characterized by a unique identifier, an initial position, velocity, field of view, and the task to which it is assigned. It is also assumed that each robot has the knowledge about its own cost of the task from the beginning, but a robot does not know about the cost of other robots as it does not know about their positions.

1.5 Rationale and Significant

The impact of this project is to help the robot developer to have a good technique of multi robot task assignment in the workspace in order to delegate task among others before achieving the desired point. The project is intended to improve the efficiency of robot motion by taking the shortest path from the initial point to prime target.

The significant of the research is to study the possibility detection of the near waypoint to be detected to reach the prime target in minimum time by considering all criteria stated before.

1.6 Project Outline

The thesis comprise in 5 chapters together including Chapter 1 is on Introduction, Chapter 2 is Literature Review, Chapter 3 is Methodology, Chapter 4 contains result and discussion followed by last chapter which is Conclusion.

Chapter 1 will discuss the introduction of the thesis by outlining the overview of the project. It will start with problem statement, objectives of the project, the project scope and the impact and significant of the project.

In Chapter 2, it reviews the previous works from thesis, journals, conference paper and experiments that related to the project. The literature review includes Multi Robot System, Multi Robot Task Allocation, Market Based Method and Shortest Path Algorithm.

Chapter 3 represents the research methodology of the project. The step by step procedure used to run the project will be explained in details. It will also include the flowchart of processes involved in software development of entire project.

Chapter 4 will contain the simulation results and its respective analysis. The result will be discussed and explained with the aid of diagrams. The comparison of every finding will be explicated in detail.

In Chapter 5, it will summarize the overall project and suggest the future recommendation to be improved in the research field.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses several algorithms that have been studied regarding multi robot task allocation problem. Among a variety of task allocation problems studied in multi-robot systems (MRS) and some related domains, works are selectively introduced based on the outstanding achievement and improvement in MRTA and have similarity to the aim of this thesis.

The chapter begins with defining the MRS and the emergent growth of the robot system. Then, it discusses the different types of task allocation methodologies for multi robot system based on task model, solution model, and magnitudes used in the cost function of algorithms. The taxonomy of problems and relevant concepts from related areas are presented. Finally, the chapter ends with the summary of the related work.

2.2 Multi Robot System (MRS)

Over the past decade, a significant shift of focus has occurred in the field of mobile robotics, for example, human assistance, urban search and rescue, topological navigation, and multi-robot data retrieval [6]. The advantages of multi-robot systems over single-robot operations include faster task completion, increased robustness, higher quality solutions , and the completion of task impossible for single robots [1]. Nowadays trends, researchers began to investigate on multiple robot rather than single robot and employed in a variety of applications that require complex coordinated tasks. From early work on simple loosely-coupled tasks such as foraging [7] to work on military purposes [5], [8].

Multi robot system (MRS) can be defined as a set of robots working collaboratively in the same environment to achieve system goals [9]. Dangerous or hazardous environment which are not suitable for human being such as removing toxic waste, exploring planets, and removing landmines may require the use of robots [8]. It is difficult to classify MRS in level of autonomy [9] as robotic systems may range from simple sensors up to complex humanoid machine, but it can be characterized in the following aspects:

i) the rationale for the design of the MRS;
ii) the basic functionalities and technologies (both hardware and software) used in the MRS development;
iii) the tasks that the robots should perform and the intended application domains.

Besides these aspects to be considered, interaction between the robots also important as it narrowed down the MRS application. The challenge to determine the suitable method/algorithm to program the robot system become more easier when we first understand the primary types of interactions that can occur in typical applications. These common forms of interaction are [10]; (i) collective, (ii) cooperative, (iii) collaborative and (iv) coordinative as illustrated in Figure 2.1.

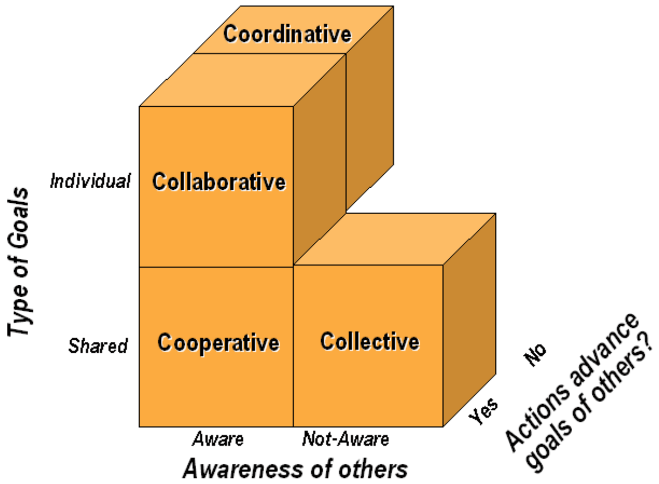

Figure 2.1: Interaction types in multi robot systems [10]

Collective interaction is the simplest type of interaction among the four, in which a set of robots do share goals and their actions are beneficial to their teammates, but they are not aware of other members on the team. An example of this type of interaction [11], the work focuses on creating systems of robots that can perform biologically-relevant tasks, such as foraging, swarming, flocking, herding, formation-keeping, and so forth. Combination of larger numbers of robots results in the global goal being achieved.

While cooperative interaction leads robots to share their goals and do aware of other entities. In multi-robot systems, an example of this type of interaction is multiple robots working together and reasoning about each other's capabilities in order to accomplish a joint task. The fundamental question: "which robot should execute which task?" always being asked by researchers that interest in cooperative robot system [12]. In [13], the multi-robot system is entitled to box pushing task where they allocate and coordinate tasks that require tightly coupled cooperation among the robots and it must do so in a fault-tolerant manner.

Apart from sharing goal, collaborative interaction makes robots work with individual goals, they are aware of their teammates, and help each other to achieve their individual, yet compatible goals. A multi-robot example of a collaborative team is a group of robots that each must reach specified goal positions that are unique to each member. If robots are unable to reach their goal positions independently, due to sensor limitations, they could work together with other robots by sharing sensory capabilities to help all team members reach their individual goal locations [10]. This type of collaboration is sometimes called coalition formation, and has been illustrated in [14].

Finally, coordinative interaction, where robots are aware of each other but they do not share a common goal and their actions are not helpful to other team members. The only sharing part for coordinative interaction is working workspace.

The robots must work to coordinate their actions to minimize the amount of interference between themselves and other robots. Multi-robot path planning techniques or traffic control are commonly used in these domains.

2.3 Multi Robot Task Allocation (MRTA)

Multi Robot Task Allocation (MRTA) is defined as the problem that determines which robot should execute which task [12]. The purpose of task allocation is to assign individual tasks to robots so that the performance of the system will be greatly enhanced, which can minimize the overall operation cost or maximize the system utility [1], [8]. In other words, MRTA problem is to find the most productive and efficient way to assign tasks to robots in order to achieve the system goal.

In [6], MRTA problems are categorized in three directions: task model, solution model, and magnitudes used in the cost function of algorithms. Task model has been viewed in three specific aspects: centralized versus decentralized, homogeneous versus heterogeneous and MRTA model.

2.3.1 Centralized versus Decentralized

Centralized multi-robot systems differ from decentralized multi-robot systems by having a central controller which is responsible for managing all the available resources. In the centralized approach, a single agent works as a leader and controls the behaviour of the entire group [9]. Each robot needs to communicate with central planner in order to compute its allocation and the information is broadcasted to whole team. But, if the communication is lost, the system meets a failure. The main advantage of centralized approach is the ability to produce an optimal planning since a decision making agent utilizes the relevant information from all robots, thus making it much easier for the system. This method is suitable for time-optimal task allocation. The centralized approach is illustrated in Figure 2.2 below.

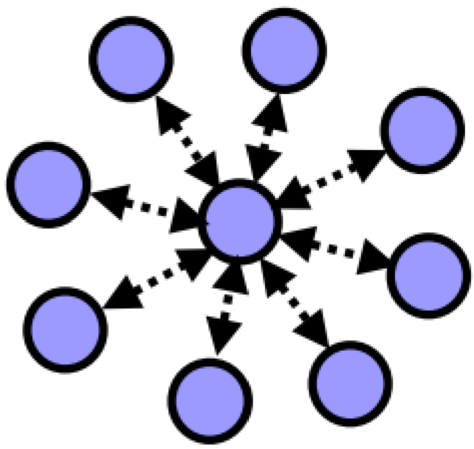

Figure 2.2: Illustration of centralized coordination of a team

While decentralized method requires no central agent, thus makes no common communication facility, thus make the algorithms become more scalable than the centralized ones. The robot has knowledge of its own state and its immediate environment. Decentralized method also known as distributed approach. This approach uses multi task selection instead of multi task allocation because the robots select the tasks instead of being assigned a task by a centralized planner or temporal agent.

Distributed approaches can be differentiated further by the architecture through which robots coordinate: behaviour based architecture; swam intelligence based architecture; and market based architecture. The basic concept of behaviour based architecture is that a collection of behaviours that perform certain goals can be tailored to the domain. Robots select the behaviours according to the current state of a team and an environment. The robots can also execute several tasks at the same time by conducting multiple behaviours in parallel. In [7], the concepts has been applied for formation control inspired from a flock of bird and schools of fish and being tested for DARPA's HMMWV-based Unmanned Ground Vehicles.

Swam intelligence based architecture is inspired by biology, especially the collective behaviour of insect colonies like ants and wasps. The ant system algorithm employs artificial pheromone, like real ants use pheromone for path selection in ant colony, as a clue for agents to make decisions.

While in market based approach, robots are designed as self-interested agents that operate in a virtual economy [1]. Both the tasks that must be completed and the available resources are commodities of measurable worth that can be traded like auction and bidder. Most of decentralized systems are auction-based algorithm such as prim allocation algorithm [15], Markov decision process [16] and S+T algorithm [17].

Table 2.1 summaries the characteristics of swam intelligence and market based approach which clearly differentiate the application of them.

Table 2.1 The differences between Swam Intelligence and Market Based Approach

Swam Intelligence	**Market Based**
Used for large scale multi – robot system	Used for small – to – medium scale task allocation
The mechanism adopts a hierarchical architecture	Better scalability and well – suited to distributed robotic domain
Example algorithms: 1. Ant colony optimization	Example algorithms: 1. First – price Auction

2. Particle swarm & ant colony optimization	2. Dynamic Role Assignment 3. Murdoch
Good features: 1. Self-organizing ability in unknown environment 2. Emergent and adaptive behaviour through simple interaction among individuals 3. Used implicit communication 4. Used robot coalition which robots cooperate to complete task – pushing box	Good features: 2. Robots act as self-interest agent and bid for tasks 3. Robot with highest bid win and get the task 4. Bids are adjusted to robot interest (capacity) to carry out the goal 5. Need communication mechanism between robots

2.3.2 Homogeneous versus Heterogeneous

A team of robots can be composed of either homogeneous or heterogeneous members. Robots in a homogeneous team have identical skills and do share the same capacities. The characteristics make the algorithms designed for homogeneous groups much easier compared to heterogeneous team. VC TA algorithm [18] is implemented in vacancy chain where it demonstrates how Reinforcement Learning can be used to make vacancy chains emerge in a group of Behaviour-Based robots. However, the advantage of homogeneous team causes wasting of resource and the lack of practical applicability[6], [8].

Heterogeneous robot team members play different roles as sometimes they differ in physical capabilities depending on hardware and control software installed as in team games where robots play different positions.

Heterogeneity arises from functional rather than physical differences [7]. Heterogeneity is highly advantageous for several reasons. First, complex missions often have many different functional requirements and can be achieved more effectively by a team of specialists rather than by a team of generalists that perhaps

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