Compound Task Allocation in Preference-based Multirobot Coordination

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Abstract

Market-based multirobot coordination has been widely used in the multirobot task allocation research. However, the existing methods consider neither various types of bid elements nor the sequential or parallel relationship of the tasks. In this paper, preference-based compound task allocation with an extended framework is proposed for multirobot coordination on the basis of the market-based approach. Three different types of the compound tasks are defined and their corresponding auctioning algorithms are proposed along with the bidding algorithm. The effectiveness of the proposed scheme is demonstrated through the simulation experiment.

Keywords–multirobot coordination; compound task; auctioning algorithm

I. Introduction

The market-based coordination approach for multirobot systems has been widely used in exploration [1]-[5] and dynamic team formation [6]-[8]. In the case of the exploration application, most of the existing methods for task allocation use either the estimated distance or time of the robot to perform the task, without considering the different capabilities of the robots. In dynamic team formation research, on the other hand, the capabilities of the robots are mainly focused for task allocation, and the spatial or temporal situation of the robot, such as estimated distance and time to perform the task is not much taken into account. To deal with these issues, this paper proposes preference-based compound task allocation for multirobot coordination. In the extended framework, robot capability matrix is used to explicitly represent the quality and cost of each capability and available capabilities of the robot and task requirement matrix is defined to denote the required capabilities for performing the task. Also, four bid elements, such as task capability quality, task capability cost, task distance and task time, are defined for the bidder such that it can explicitly inform the auctioneer of its competence on the auctioned task. The preference-based task allocation was introduced in [9], and this paper extends the preference-based task allocation for the compound task allocation.

II. Task Allocation

A. Compound Tasks

The compound task consists of atomic tasks and three types of compound tasks, such as sequential, parallel and hybrid ones are defined depending on the relationship among the atomic tasks. The sequential compound task, SCT consists of the atomic tasks which need to be performed sequentially. It is defined as T^{SCT}. The parallel compound task, PCT is defined as the following combination of the atomic tasks which are required to be performed in parallel. It is denoted as T^{PCT}. The hybrid compound task, HCT contains the atomic tasks which can be performed either sequentially or in parallel. It is defined as T^{HCT}

B. Auctioning Algorithms

The auctioning algorithm for each compound task must satisfy its constraint. In the case of SCT, the atomic tasks should be auctioned sequentially, one at a time. In the case of PCT, the atomic tasks are auctioned in parallel, where there are two relationships, such as one atomic task should be allocated to only one robot and one robot can get only one atomic task. In the case of HCT, the atomic tasks should be auctioned concurrently, where there is one constraint that one atomic task should be allocated to only one robot.

1) The Auctioning Algorithm for SCT: Let N and M be the set of bidders and the set of the atomic tasks in SCT, respectively and U_{ij} be the utility value of $Robot_i$, $i \in N$, for T_j^{SCT}, $j \in M$. The definition of the utility of the robot for the task is defined in [9]. The task allocation problem for SCT can be formulated as

$$U = \max_i U_{ij} \tag{1}$$

$$\text{for} \quad \forall i \in N \quad \text{and} \quad \forall j \in M.$$

To maximize U, each atomic task should be allocated to the bidder which has the highest utility value. This allocation is categorized as ST-SR-IA: single-task robots, single-robot tasks and instantaneous assignment [10]. Since the sequence of the atomic tasks are predefined as their priority, the auctioneer makes an auction call for a single atomic task at a time, and the bidder bids on it. After the auctioneer receives the message from an assigned bidder that the allocated atomic task has been completed, it then makes an auction call for the next one. For example, consider a floor cleaning SCT with sweeping and mopping atomic tasks. The auctioneer first holds an auction for the sweeping atomic task. After the auctioneer receives the task completion message, it then hold an auction for the mopping atomic task. Therefore, the bidder only considers currently auctioned atomic task when it generates the bid list.

2) The Auctioning Algorithm for PCT: The task allocation problem for PCT can be formulated as

$$U = \max \sum_{i \in N} \sum_{j \in M} s_{ij} \cdot U_{ij} \tag{2}$$

where

$$\sum_{i \in N} s_{ij} = 1 \quad \text{and} \quad \sum_{j \in M} s_{ij} = 1.$$

The auctioneer should allocate the atomic tasks with maximizing U while keeping two constraints above. The first constraint ensures that one atomic task is assigned to only one bidder and the second guarantees that one robot can take only one atomic task. This is categorized as ST-MR-IA: single-task robots, multirobot tasks and instantaneous assignment [10]. The bidder can bid on more than one atomic task as far as it has all the required capabilities for them. However, at most one atomic task should be assigned to one robot and one robot can only have one atomic task. For example, suppose that a task carrying a large-sized box consists of left and right lifting atomic tasks. Even if one robot has enough capabilities for lifting either side of the box, it should not take both of them since it can not perform them simultaneously.

3) The Auctioning Algorithm for HCT: The task allocation problem for HCT can be formulated as

$$U = \max \sum_{i \in N} \sum_{j \in M} s_{ij} \cdot U_{ij} \tag{3}$$

where

$$\sum_{i \in N} s_{ij} = 1.$$

The above constraint ensures that one atomic task is assigned to only one bidder. Unlike the case of PCT, one robot can have more than one atomic task. This is categorized as either ST-SR-TA or ST-MR-TA: single-task robots, single-robot tasks and time-extended assignment or single-task robots, multi-robot tasks and time-extended assignment [10]. For example, suppose that the room cleaning task consists of $Room_1$ and $Room_2$ cleaning atomic tasks which do not have any sequential or parallel relationship. Therefore, one robot can perform both atomic tasks sequentially by itself, or two robots can perform them in parallel.

C. Bidding Algorithm

The bidder should be able to consider different types of compound tasks to get the atomic task from the auctioneer. After receiving the awarded atomic task and utility value for it from the auctioneer, the bidder stores the utility value in the utility value set, G, resets the bid timer, $BidTimer$ and runs it until it reaches the bid closing time, $ClsTime$. The bidder then selects the awarded atomic task which has the highest utility value in G and accept it.

III. Simulation Experiment

In the simulation experiment, a cleaning mission was provided to demonstrate the effectiveness of the proposed scheme. As the extension of the cleaning mission in [9], the procedure of the mission is as follows. There are two rooms, $Room_1$ and $Room_2$, and two types of blocks, red and blue blocks, are randomly located in the rooms. The blocks in $Room_1$ and $Room_2$ are collected and carried to $Tray_1$ by the robots, and $Tray_1$ is carried to the hall by two robots. After moving the tray, the blocks are sorted by their color and the red blocks and the blue blocks are carried to $Tray_2$ and $Tray_3$, respectively. To carry loaded trays to designated zones, the gate of $Room_3$ is unlocked and pushed. Finally, $Tray_2$ and $Tray_3$ are carried to $Zone_1$ and $Zone_2$, respectively.

To carry out the mission, five compound tasks are provided for the mission in Table I.

TABLE I
THE DESCRIPTIONS OF COMPOUND TASKS.

Compound task	Description	Atomic tasks
T_1^{HCT}	Move blocks in rooms to $Tray_1$	$\{T_1^A, T_2^A\}$
T_2^{PCT}	Carry $Tray_1$ to $Hall$	$\{T_3^A, T_4^A\}$
T_3^{HCT}	Sort blue and red blocks	$\{T_5^A, T_6^A\}$
T_4^{SCT}	Open the gate of $Room_3$	$\{T_7^A, T_8^A\}$
T_5^{HCT}	Carry trays to $Zone_1$ and $Zone_2$	$\{T_9^A, T_{10}^A\}$

A. Results

The connection of the atomic tasks from the result of the task allocation shows the characteristics of different types of preference-based task allocations. Figs. 1, 2 and 3 show the connection of the atomic tasks, when QB and CB, DB and TB were used, respectively. As shown in Fig. 1, when QB and

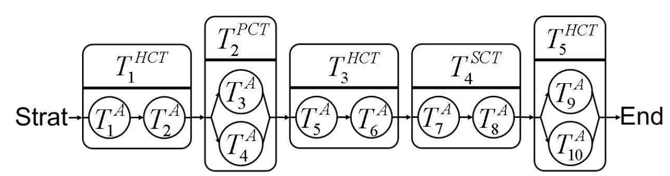

Fig. 1. The connection of the atomic tasks when QB and CB were used.

CB were used, all of the atomic tasks in HCT were connected sequentially.

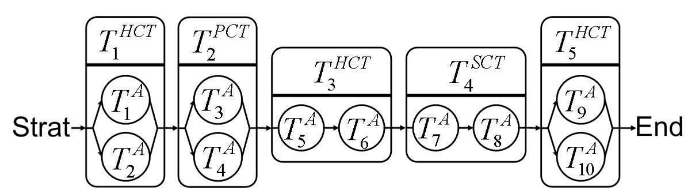

Fig. 2. The connection of the atomic tasks when DB was used.

Fig. 2 shows the connection when DB was used. As shown in the figure, the atomic tasks in T_1^{HCT} and T_5^{HCT} were connected in parallel, which implies that they were allocated to two different robots, and the atomic tasks in T_3^{HCT} were connected sequentially, which implies that they were allocated to the same robot.

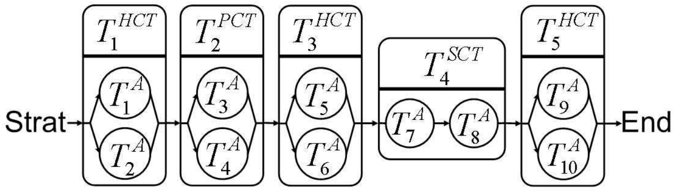

Fig. 3. The connection of the atomic tasks when TB was used.

Fig. 3 shows the connection when TB was used. As shown in the figure, all of the atomic tasks in HCT were connected in parallel, which implies that they were performed in parallel by different robots. This is because TB considers more on minimizing task completion time for performing a task than any other aspects.

IV. Conclusion

This paper proposed preference-based compound task allocation with an extended framework for multirobot coordination. In order to specify the relationship of the atomic tasks, three different types of the compound tasks, such as sequential, parallel and hybrid ones, are defined and the corresponding auctioning algorithms are proposed along with the bidding algorithm. In the simulation experiment, a cleaning mission, which consisted of five compound tasks, was provided and the quality, cost, distance and time-based task allocations were applied to the mission. The simulation results demonstrated that the proposed scheme could effectively allocate the tasks for completing the cleaning mission to the robots considering the bid values and auctioneer's preference for bid elements.

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