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Multi-Robot Foraging Based on Contract Net Protocol

Adel Akbarimajd[1] and Hossein Barghi Jond[2] *

1) Department of Mechatronics Engineering, Ahar Branch, Islamic Azad University, Ahar, Iran
2) Young Researchers and Elite Club, Ahar Branch, Islamic Azad University, Ahar, Iran

adelakbary@yahoo.com; h_jand@yahoo.com

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Abstract

Because of high speed, efficiency, robustness and flexibility of multi-agent systems, in recent years there has been an increasing interest in the art of these systems. In competitive multi agent systems, a mechanism is required via which the agents can come to reach an agreement. Contract net protocols are one of the well-known negotiation protocols in multi-agent systems. In contract net protocol, each agent can be a manager or a contractor. The managers announce available tasks and the contractors bid over the tasks. Then, the managers investigate received bids and decide which contractor could perform the task. The decision is made based on an eligibility function. In this paper, a multi robot foraging problem is considered where mobile robots with limited energy resource try to transport some moving objects to a collection point. The problem is modeled as a contract net system and then solved. Efficiency of the algorithm and optimality of solutions are investigated by provided examples and simulations.

Keywords: *Distributed Artificial Intelligence; Multi-agent systems; Contract Net Protocol; Foraging Robots*

1. Introduction

Despite having some advantages, multi-agent systems encounter some new challenges corresponding to task allocation, cooperation and coordination problems [1],[2]. In a multi-agent system, a total task is decomposed into some sub-tasks and each agent undertakes a subtask. In fact, agents perform their own jobs while completing the whole task of the mechanism. Agents may communicate, cooperate and/or coordinate with other agents during their duty times. Therefore, it is desirable to find efficient methods and algorithms for task decomposition, task allocation, cooperation and coordination of agents in multi-agent systems.

Contract net protocols are one of the frequent market mechanism protocols [3]. Sometimes in a contract net, each agent can be manager or contractor if required. In this protocol, manager agents announce an available task to other agents that operate as contractors. The contractors bid over the tasks if they are interested to do it. Then if the manager accepts the bid (according to a specific eligibility criterion) a contract is formed and the task is performed by the contractor agent.

Contract nets implementation into a control system in a discrete manufacturing environment [4], different contract types analysis by a task allocation graph [5] and using as a distributed task allocation scheme in multi-UAV robots [6], proposing a model to ease the bid evaluation to handle tasks with complex process structure [7], coordination of agents in multi-agent system [8], job scheduling service model based on contract nets negotiation protocol [19], are some important literatures. Also, it was shown that the behaviour of the protocol depends on the system size and agent load and under heavy loads, the algorithm usually should be performed frequently [6]. Improved versions of contract net are debated in [11]. As it can be seen from above literature, contract nets have been employed in many real-world applications. Apart from literature, we employ contract nets in multi-robot foraging systems.

In this paper, we consider a multi-robot foraging problem as a good setup in multi-agent systems. In the foraging problem, some mobile robots try to collect some objects to a specified goal point. In typical foraging problems, the robots are assumed to have infinite energy resource, however in our problem, the robots have limited fuel and limited sensory information which are considered as constraints. We develop a contract net protocol via which the agents can reach an agreement about carrying the objects. Each agent is assumed to be a self-interested agent trying to maximize its own profit; but the agents are constrained to operate in the framework of the proposed negotiation algorithm which would lead to maximum profit of the whole system.

The rest of the paper is organized as the following. In the next section, multi-robot foraging problem is described as a contract net system. Third Section includes simulation results. Conclusions are provided in the last section.

2. Multi-robot foraging problem as a contract net

Firstly, we introduce fundamentals of contract nets as a mechanism for modeling and decision making purposes in multi-agent systems. In contract net, there are two types of agents including managers and contractors. Managers announce tasks to be performed to the society. Contractors announce whether they are interested to perform tasks or not. Then the managers decide which contractor should perform which task. The roles of agents are not specified in advance and during the algorithm role of an agent can be changed from manager to contractor or vice versa. Decision processes of manager and contractor agents and task announcement details is shown at Table 1 and 2, respectively.

Table 1. Decision processes of manager and contractor agents.

Manger's decision process:	Contractor's decision process:
announce a task	receive announcements
receive and evaluate bids	respond (decline, bid)
award a contract to a suitable contractor	perform the task if his bid is accepted
receive and synthesize results	report his results

Table 2. Details of a task announcement in contract net protocol.

Filed name	Description
Addressee	includes one or more potential contractors
Eligibility function	criteria of the eligibility specification of potential contractors
Task abstraction	a brief description of the task
Bid specification	tells contractors what information must be provided with the bid
Expiration time	a deadline is required for receiving bids

2.1 Problem description

Lets us assume that R robots are located in an environment in different locations $\mathbf{P}_{Ri}=(X_{Ri},Y_{Ri})$. The robots should collect the objects from positions $\mathbf{P}_{Oj}=(X_{Oj},Y_{Oj})$ to a single goal point $\mathbf{P}_G(X_G,Y_G)$. The objects are static and may be carried by a single robot or by a team of robots. Robot i initially has limited fuel F_i. The fuel consumption rate of the robots while travelling with no load is E_f unit per meter. If a single robot carries a single object, it would consume E_c unit of fuel per meter and if n robots cooperate in carrying an object, the rate of fuel consumption will be decreased to E_c/n unit per meter for each robot. A fuel station is located at $\mathbf{P}_F=(X_F,Y_F)$. Only agents (robots) those have contributed in collecting the objects are allowed to fuel after completing the collection task. Each robot has its local database including its own position and the positions of the goal and fuel station. Database of each agent does not include positions of the other ones.

2.2 Modeling the problem as contract net

To solve the problem by contract net protocol, we specify the components of the contract net as Table 3.

Table 3. Components of the proposed contract net protocol.

Filed name	Description
manager	that the robot who firstly finds the object acts as a manager.
task abstraction	the transportation of the object. The task is specified as *Task*=[j,X_o,Y_o], where j is the number of robot who is the manager (j=1,...R) and X_o, Y_o are coordinates of the identified object.
contractor	All robots in the environment are potential contractors.
eligibility function	For carrying an object i, each robot (j=1, ..., R) calculates the following value as it eligibility, $E_i^j = F_j + O_i^j - C_i^j$ where E_i^j denotes eligibility of robot j, F_j is the initial fuel of the robot j, O_i^j is the amount of fuel the robot receives from the fuel station if it contributes in carrying the object. C_i^j is the fuel consumed by the robot if it transports the object.
bid specification	The bid is specified as *Bid*=[j,i, E_i^j], where j shows the robot who has placed the bid and i shows the object for which the bid is placed.
expiration time	If the contractor gets no bid after a specified time, it will carry the object by itself.

3. Simulations

In the simulations, in order to verify suitability and efficiency of the proposed method, we considered an environment with only one stationary object. The environment includes *200m Í 160m* area with 7 robots whose initial locations are shown in Table 4. The rate of fuel consumptions with and without carrying the object is assumed $E_f=0.07$ and $E_c=0.7$, respectively. It is assumed that initial fuel of robots is *750* $(F_i=750\ i=1,...,R)$. Available fuel at station is set to 800. We applied the proposed method for two problem cases with different values for locations of the object, goal point and fuel station are illustrated in Table 5.

In problem case 1, robot 5 is the closest to the object, hence it acts as manager. After announcing the task and receiving the bids, robots 3, 4, 5 are awarded and they contribute in carrying the object (see Figure 1). In problem case 2, robot 1 is manager and by contract net protocol, robots 1, 3, 4 are decided to contribute in carrying the object (see Figure 2). In Table 6, fuel consumption of the society corresponding to obtained decision is compared with the optimal solution. In this simple example the optimal solution is obtained by a brute force method, where all possible solutions are calculated and the best one is selected. In case 1, fuel consumption corresponding to the decision of the proposed method 703.05 is about 7%, more than that of the optimal solution (653.45). In case 2, fuel consumption corresponding to the decision of the proposed method 665.82 is equal to that of the optimal solution. It is noteworthy to mention that in distributed decision systems where no agent has full information about the environment, optimal solution is not expected and near-optimal solutions are satisfactory.

Subsequently, initial values of robot fuels is changed to ($F_1= F_2= F_6= F_7=800$, $F_3= F_4=F_5=300$) and available fuel at fuel station is changed to $S=900$. Different initial fuels and different outcomes would cause different results. By changing robot fuels in the problem case 1, agent 6 has become interested in participation in foraging task. As a result, agents 3, 4, 5, 6 are included in the final decision (see Figure 3). In the same way in problem case 2, agent 5 has become interested to participation in foraging task and agents 1, 3, 4, 5 are included in the final decision (see Figure 4). In table 7, optimal solutions are compared with solutions obtained by the proposed method. Fuel consumptions in solutions given by the proposed method are 10% and 3%, more than the optimal solutions of problem cases 1 and 2, respectively.

Table 4. Initial positions of agents. Pi=(Xi,Yi) is position of ith agent.

P_1	P_2	P_3	P_4	P_5	P_6	P_7
(30,140)	(50,40)	(70,100)	(100,150)	(120,70)	(180,120)	(200,20)

Table 5. Positions of goal, object and fuel station in two problem cases studied in simulations.

CASE	Goal position $\mathbf{P}_G=(X_G,Y_G)$	Object position $\mathbf{P}_O=(X_O,Y_O)$	Fuel station position $\mathbf{P}_F=(X_F,Y_F)$
1	(10,70)	(110, 90)	(190,70)
2	(160,10)	(60,160)	(90,20)

Table 6. Comparison of optimal solution and the solution obtained by the algorithm (first set of fuels)

	Optimal solution		**Solution given by the proposed method**	
	Awarded Robots	Fuel Consumption	Awarded Robots	Fuel Consumption
Problem Case 1	3, 4, 5	703.05	3, 5	653.45
Problem Case 2	1, 3, 4	665.82	1, 3, 4	665.82

Table 7. Comparison of optimal solution and the solution obtained by the algorithm (second set of fuels)

	Optimal solution		**Solution given by the proposed method**	
	Awarded Robots	Fuel Consumption	Awarded Robots	Fuel Consumption
Problem Case 1	3, 4, 5, 6	703.05	3, 4, 5	782.87
Problem Case 2	1, 3, 4	665.82	1, 3, 4	685.88

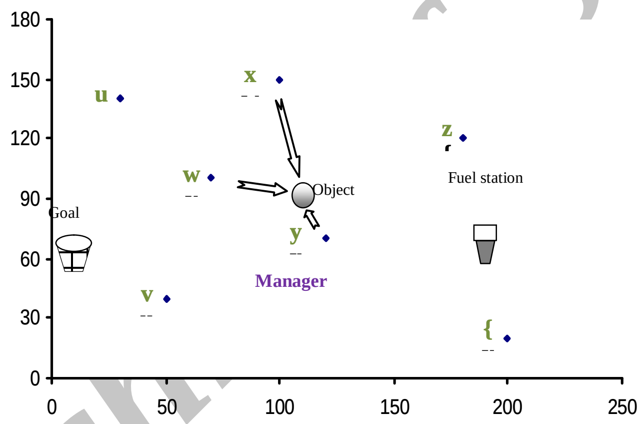

Figure 1. Solution of problem case 1 (first set of fuels)

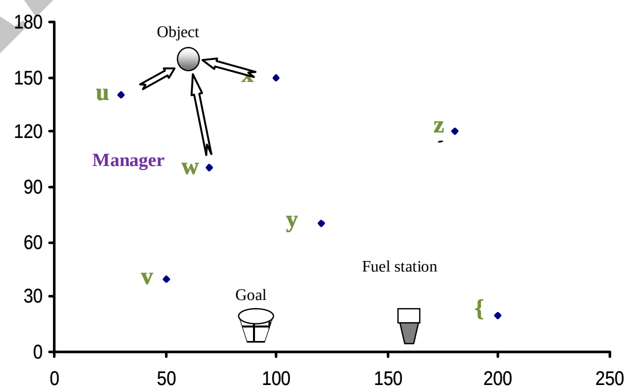

Figure 2. Solution of problem case 2 (first set of fuels)

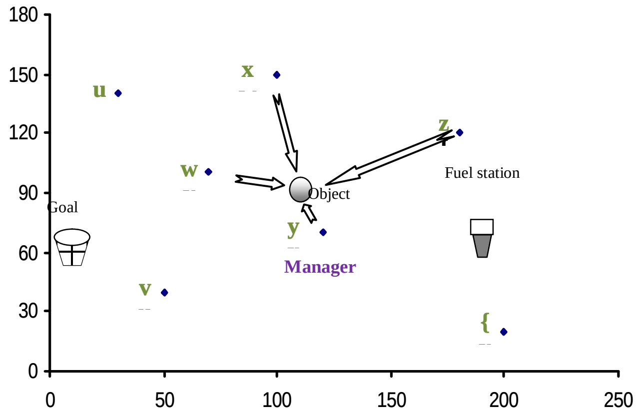

Figure 3. Solution of problem case 1 (second set of fuels)

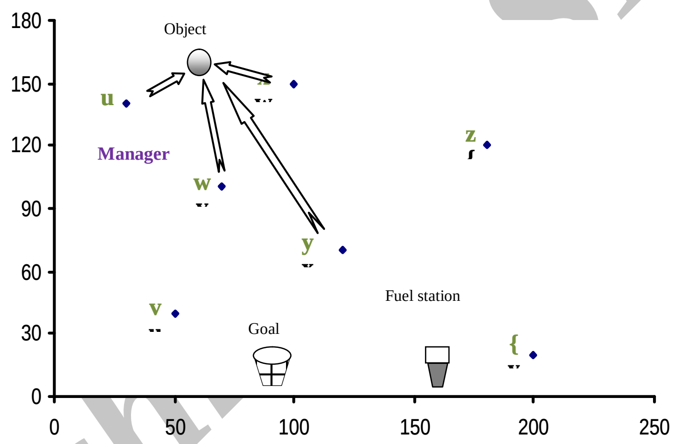

Figure 4. Solution of problem case 2 (second set of fuels)

4. Conclusions

Multi-robot multi-object foraging problem can be a good test bed for multi agent problems. The problem would be more complicated when the energy resources of the robots are limited and the robots have to consider this constraint in their decisions. In this paper, a limited resource multi-robot foraging problem was considered and modeled as contact net. Components of the contract net to solve the problem were devised. Simulations in MATLAB were show that the solutions obtained by the algorithm are near optimal in the environment with static objects.

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