COALITION FORMATION AND TASK ALLOCATION OF MULTIPLE AUTONOMOUS ROBOTS

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Abstract—Multi robot systems are of increased demand in industrial environments for easier task execution in short durations. The challenge in deploying a multi robot system for task execution lies in coordinating the robots to perform a task collaboratively within the stipulated time. This paper deals with the following challenge in the multi robot system, first is the search for the most optimal solution for coalition formation, which acquires ample information about the task and the robot agent used, followed by allocating tasks to the robots in the coalition which is commonly referred to as Multi-Robot Task Allocation (MRTA) problem. The optimal solution for robot coalition lies in determining the best number of robots required to complete the task within the deadline that is achieved using dynamic ANT coalition technique which works online. The novelty of the proposed methodology lies in using the most effective local search process of the memetic algorithm rather than using the whole of the memetic algorithm which includes the global search and local search process.

Index Terms—Coalition formation, dynamic ANT coalition, task allocation, memetic algorithm

I. INTRODUCTION

The scale to which humans are tend to be replaced with robots are yet to be measured distinctively. One way through which robots need to be a better replacement for humans in the area of co-operative working. Automation in industries is developing at rapid rate to increase the production rate and accuracy. Automation at this level is obtained by deploying manually controlled robots and autonomous robots. Manually controlled robots require a human operator to control the activities and movements of the robots. Autonomous robots are the need of the hour with least human intervention with requires only supervisory control over the robots, unlike the manually controlled robots. Autonomous robots are self-deciding robots, executing tasks without a human controller controlling the action of the robot. When complex tasks are to be executed by a single autonomous robot there are possibilities that the completion of the task might take longer time than the deadline to be met and one point failure might lead to a collapse of the entire system. Hence we go on to deploy multiple robots to execute complex tasks. The challenge in multi-robot system is allocating tasks.

Multi-robot systems are becoming increasingly more capable and the types of achievable applications for teams of robots are becoming progressively more complex. Recent research trends and technology developments are bringing us closer to the realization of autonomous multi-robot systems performing increasingly complex missions. Existing algorithms for task allocation treat tasks are indivisible and fail to address the specific details of tasks.

A. Coalition Formation

The basic principle behind this new approach to the robot coordination was directly inspired by the observation of natural systems. In nature, in fact, it is possible to see a lot of animals that work together for a final common purpose: typical example can found in the sea, on the ground and in the air, and more evolved animals can collaborate to perform more complex social behaviors. ANTs and termites can work together to build enormous nests or to transport a prey that is many times heavier than the individuals; birds can fly in compact formations during migrations in order to save energy, and fishes school in groups with thousand individuals to protect from enemies.

Complex real-world task requirements especially surveillance of non-deterministic environment often surpass the capabilities of a single robot; therefore, coalitions are necessary. Various existing approaches for coalition formation don’t result in optimal solution. Forming efficient robot coalitions for surveying non-deterministic environment requires accommodating appropriate spatial constraints. The distance between coalition members and the assigned task’s location is critical, since robots must travel to the task location before performing the task and complete the task before the deadline. Hence those robots that are near to the task location must be selected and also the resource availability must be considered. Coalition formation is dependent on the type of task and the nature of the robot. Each robot has unique feature in an heterogeneous multi-robot system. The coalition team formed is supposed to meet the entire requirement of the task.
B. Task Allocation

Multi robot task allocation means to distribute and schedule a set of task to be accomplished by a group of robots to minimize cost while satisfying operational constraints. It can be challenging to solve a large number of tasks and becomes even more challenging when tightly coupled multi robot task are also taken into account. The problem of task allocation in multi-robot systems has received significant and increasing interest in the research community. Task allocation is specific to a particular problem and it has to be explicit. When the allocation is done skillfully it provides an efficient solution for the problem of coordinating robots in a swarm. The solution obtained is specific to a problem but if robots are to be used for a variety of purpose they must be capable of solving a variety of problems.

This paper presents a dynamic ANT coalition approach that addresses the combinational coalition formation problem. Section II describes the coalition formation problem and cooperative task allocation to the set of selected robots. The dynamic ANT coalition technique and memetic algorithm is detailed in Section III. Section IV provides the experimental results and conclusions are presented in Section V.

II. RELATED WORK

Coalition formation is of non-deterministic nature and its performance depends on various parameters. The formal analysis of task allocation in multi-robot environment [1] Several heuristic-based coalition formation algorithms have been proposed. ANT colony optimization (ACO) is an iterative; swarm based biologically inspired search approach that was proposed as the ANT System and applied to the Traveling Salesmen problem [3]. ACO is motivated by ANT foraging behavior and the use of pheromones as an indirect, local, and non-symbolic mode of communication employed to exchange information via the environment. ACO has been extensively used to address difficult problems, such as resource-constrained scheduling [7] and classification. Nevertheless, ANT colony optimization suffers from two major disadvantages: firstly search inaction in local optima that often results in sub-optimal solutions, and secondly necessity of a large number of iterations for solution convergence leading to greater computational time. Extensions to the approach leverage an elitist strategy [3]. ACO rankings [1], and bounded pheromone levels [13]. The distance between coalition members and the assigned task’s location is critical, since robots must travel to the task location before performing the task and complete the task before the deadline. Hence the robots that are near to the task location must be selected and also the resource availability must be considered. Game theory approaches have been proposed which are used in cost saving games where individual cost functions of players have certain characteristics.

MRTA for surveillance problems can be described as a complete task assignment for a group of robots so that best robots could complete monitoring the region of interest. Then, the problem is modeled as optimization problems subject to restrictions. Before designing algorithms for multi-robot systems, there are two important points that should be figured out so as to complete the mission reliably. The first important thing is to understand the characteristics of the tasks and their environment, and the second is to understand the robot’s capabilities and its resource availability. The goal of MRTA for the studied inspection problem is not only to assign tasks to robots, but also to determine the task sequence for each robot under coalition constraints for two-robot tasks. Despite the fact that a multi-robot requires at most two tightly coupled robots, the complexity of MRTA greatly increases in case of more two robot tasks or dynamic planning.

III. PROBLEM STATEMENT

The coalition formation problem looks to determine the finest subset of robots based on the utility factors like cost, completed task, which satisfies the task requirements and optimizes certain objective functions.

Coalition formation:
The best robots are searched based on their capability, distance and available resource. Assume a group of \( m \) robots,

\[
A = \{a_1, a_2, ..., a_m\} \quad \cdots \cdots (1)
\]

Each robot has its own resource capability vector denoted by \( R_i \) of size \( n \), where \( r \) is the number of resource types,

\[
R_i = \{ar_{i1}, ar_{i2}, ..., ar_{in}\} \quad \cdots \cdots (2)
\]

Let \( T \) be a set of \( q \) tasks,

\[
T = \{t_1, t_2, ..., t_q\} \quad \cdots \cdots (3)
\]

where each task has its own resource requirement vector denoted by \( TR_j \) of size \( c \),

\[
TR_j = \{tr_{j1}, tr_{j2}, ..., tr_{jp}\} \quad \cdots \cdots (4)
\]

A coalition group is a team \( S_c \) of robots than can cooperatively accomplish a task where, \( s_c \in A \quad \cdots \cdots (5) \)

The resource availability of the coalition team \( S_c \) is the cumulative result of the resource vectors \( SR_c \) of the set of selected robots in the team. The coalition team is determined to be a potential team to complete the task only if

\[
SR_c \geq TR_j \quad \cdots \cdots (6)
\]
Multiple Robot Task Allocation (MRTA) can be described as a complete task assignment for a group of robots so that robots work in synchronization with each other. The problem is modeled as optimization of the objective function with the aim of minimizing or maximizing the objective variable like task completion time, communication cost, transportation cost, utility function, reward value, etc.

IV. PROPOSED METHODOLOGY

A. Dynamic ANT Colony Optimization

Dynamic ANT colony optimization is a continuous iterative search method for finding discrete optimization problem such as this. An increased number of iterations focus the search process on certain areas of the search space that are more likely to contain the optimal solution. Dynamic ANT coalition technique exploits the idea of ANT colony optimization and simulated annealing heuristic incorporates the distance of the robots from task location in order to reduce traveling distance, while reducing communication cost and loss of robot resources. ANT colony optimization extends ANT-Coalition in order to generate very high quality task coalitions. This dynamic technique leverages the simulated annealing technique to dynamically modulate the depositing of pheromones to increase the search exploration. The proposed coalition algorithm tries to reduce the coalition members’ communication expenditure, and finally robots that are spatially close tend to form coalitions irrespective of the task location. Unlike simulated agents, real-world robots must travel to the task location before performing the task; therefore, minimizing the required traveling distances for the coalition robots is crucial. Dynamic ANT Colony optimization minimizes the robots’ traveling distances, while computing efficient robot coalitions.

B. Memetic Algorithm:

Memetic algorithm consisting of global and local search schemes is proposed to solve the MRTA problem. At the beginning of this section, the structure of the memetic algorithm is introduced. Then a genetic algorithm for global search scheme is designed. After that local search schemes are introduced in order to improve the efficiency of the task allocation to the best selected robots.

C. General algorithm structure:

In this paper, a memetic algorithm is chosen for solving the MRTA problem because it combines local search efficiency with an excellent global search capability. Unlike traditional memetic algorithms the local improvement procedures of the proposed memetic algorithm are not applied to each individual within a generation. To improve the computational efficiency, the local search schemes are only applied to the best individuals in each generation. A genetic algorithm is used for the global search as it considers all obtainable information and can provide ideal solutions. The flow chart of the memetic algorithm is shown in Figure 1.

D. Modified algorithm for Coalition formation with task allocation

The global search of the memetic algorithm is used to find out the nature of the task, the environment of deployment, constraints imposed on the robots, etc. A separate search as this time consuming despite various programming strategy is used as the number of generation in the algorithm which corresponds to the number of solutions required to be found to obtain an optimal solution. In real time scenarios, even a sub-optimal solution which meets the requirements of the task and completes within the deadline is acceptable. The main requirement of hard-real time systems is that the dead line should be met. This requires the coalition formation and the task allocation to be done ahead of the time required to complete the task collaboratively. Taking this to be main consideration in the design of the combined dynamic ANT coalition and memetic algorithm.

![Flow chart of basic memetic algorithm](image)
solution obtained depends on the time limit imposed on the algorithm which is the number of allowed iterations. The number of iterations is determined by the time taken for the completion of a single iteration which varies on hardware or the processor on which the algorithm is deployed. This time limitation has to be well ahead of the time required for the task to be executed. The flow of the proposed modified algorithm is demonstrated in Figure 2.

The local search of the genetic algorithm is used to refine the solution from the dynamic ANT coalition formation which finally decides which robot executes which part of the task. It is assumed that tasks can be divided into sub-tasks and the sub-tasks are not dependent on each other.

![Flow chart of with combined coalition formation and task allocation](image)

**Figure 2. Flow chart of with combined coalition formation and task allocation**

### V. EXPERIMENTAL RESULTS AND DISCUSSION

Initially coalition formation was formed using Dynamic ANT Coalition technique. The best robots depending upon the task location and also the desired distance metric were chosen and the task was allocated accordingly. The simulation is carried out using Breve, is a 3D simulation environment designed for simulation of decentralized systems and artificial life and V-REP, which is an integrated development environment based on distributed control architecture: each object/model can be individually controlled via an embedded script, a plug-in, a ROS node, a remote API client, or a custom solution. V-REP is very versatile and ideal for multi-robot applications.

![Figure 3. Leader Robot and their slaves](image)

**Figure 3. Leader Robot and their slaves**

In Figure 3 the leader robot and its slaves are framed using Breve. The leader robot has entire database regarding each slaves with respect to the robot capability and the resource availability for each robot.

The distance between the task location and the selected robots based on the particular task is computed using the proposed technique and simulated as shown in Figure 3.

In Figure 3 and Figure 4 several subsets of the robot agents are formed as groups in which there is single leader and multiple slaves. This is similar to the birds flocking together where each bird is in a group. The groups formed here is similar to the robot agents which tend to be a sub-optimal solution.

![Figure 4. Slaves following the pheromones of the previous leader ANT](image)

**Figure 4. Slaves following the pheromones of the previous leader ANT**

In Figure 5, a real time scenario of inspection is demonstrated using V-REP software. The coalition formation and task allocation are deployed in a fire accident area. The time constraint to find injured human beings in the fire accident area is crucial. Hence the formation of the coalition and task allocation is demonstrated here. Out of the given available robot agents the best of available robots are selected and the environment is split into quadrants and given as four tasks that are not dependent on each other.
Figure 5. Coalition formation and task allocation in a simulated real time environment

The robot agents that were used are UAVs in this case which displays a red dot in the area map. The task to be accomplished by the UAVs is to locate the presence of human beings in the area that is given as task to each of UAV.

VI. CONCLUSION AND FUTURE WORK

In the field of mobile robotics, the study of multi-robot systems is now of paramount importance. Having solved some of the basic problems concerning single-robot control, many researchers have shifted their focus to the study of multi-robot coordination. The challenge in deploying coalition formation and task execution of multi robot system and coordinating the robots to perform a task collaboratively for the application of surveillance in surveyed environment within the stipulated time was successfully achieved. With the area of the destination location known, the amount of power required is estimated. Thus we have the power required for performing the surveillance task and the distance to be travelled from the source to the destination. With the available resource a simple coalition formation algorithm was deployed which required less computation time and computational power.

REFERENCES


