Multi-robot Cooperative Task Processing in Great Environment

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***Abstract*—Multi-robot coordinated control has been practical. In order to apply multi-robot coordinated control technique in cooperative task processing in a great environment, we should allocate task for robots and the robot should locate itself in the environment. To solve multi-robot task allocation and robot localization problem for coordinated multi-robot in great environment, a wireless sensor network, composed of control center, wireless gateway and wireless sensors, was presented to control multi-robot. In order to improve the working efficient of multi-robot, the efficient optimization based multi-robot task allocation mechanism was proposed; by using ant colony algorithm, the task allocation solution was got and informed to robots via wireless sensor network by the control center. By adapting Time Difference of Arrival (TDOA) based approach, the robot localization was realized in virtue of the localization information provided by wireless sensors. A wireless sensor network was set up, and containers transporting on a dock by using three robots was simulated. Simulation results shown that multi-robot coordinated control in great environment was realized so that the robots can accomplish the tasks cooperatively with the least time, and the robot localization was realized.**

***Keywords*—multi-robot task allocation, localization, wireless sensor network, ant colony algorithm, TDOA**

I. Introduction

It has been practical that tasks distributed in a great environment were implemented by some coordinated multiple mobile robots, such as transporting containers on a dock. In order to accomplish the tasks with high efficiency, we must allocate these tasks to robots. That is the problem of multi-robot task allocation (MRTA). To accomplish tasks within the least time, the tasks should be allocated with proper number of robots and inform the robot, so the communication equipment is necessary to the robot. And to process the task, the robot should locate itself in the great environment so that the robot can know where the task is. Therefore, the robots should equip with localization equipment. Therefore, multi-robot task allocation and robot localization are two important problems. In this paper, we will propose an approach to solve these two problems in virtue of wireless sensor network.

In recent past decades, MRTA has received significant and increasing interest in the research community. Many variations of local search algorithms for solving problems have been proposed and investigated. And these algorithms can be roughly classified into market-based and behavior-based algorithms. Parker[1] proposed the L-ALLIANCE system, in which each robot estimated its own performance and the performance of other robots on selected tasks, and used these values to reallocate tasks. The algorithms used in this system utilized local utility estimations to make local allocation decision. Botelho[2] proposed M+ algorithm which chose Contract Net Protocol framework to integrate mission planning, task refinement as well as cooperative mechanisms. In this work, they adopted auction theory to find an optimal solution. Werger and Mataric[3] worked on the Broadcast of Local Eligibility algorithm for task allocation, which compared locally decided eligibilities to allocate tasks with the help of Port Arbitrated Behaviors. Brian[4] proposed Murdoch system, which employed a set of matrices to score the suitability of the participating robots and publish/subscribe communication paradigm with an auction theory for task allocation. In this system, unique task monitors were also used. Luiz Chaimowicz[5] proposed dynamic role assignment architecture, which was another CNP-based approach to MRTA. T. Dahl[6] proposed an algorithm based on vacancy chains where group dynamics were considered. This is used for homogenous robots in prioritized transportation problems. In despite of these approaches to MRTA, many researchers investigated the use of SA to the similar problems. Czech[8] investigated a vehicle routing problem with time windows using a parallel simulated algorithm. Kim[9] used SA-based algorithm in Birth scheduling problem in Container port. S. Melouk[10] utilized SA for scheduling of batch processing plant to improve solution quality and to reduce computation time. These approaches also give us some clues on MRTA problems.

Robot localization method is roughly classified into GPS based approach, vision based approach, multiple sensors information fusion based approach and wireless sensor network based approach [11-15] and so on. All the approaches have been used successfully. Wireless sensor network based approach is classified into distance-based and distance-free mechanism of localization. The distance-based localization approach includes TOA based, TDOA based, AOA based and RSSI based approach [16].

Wireless sensor network is composed of many wireless sensors distributed in an area. Considering the need of communication and orientation, we will propose an approach which informs the robots the task allocation results and locate the robot in virtue of the communication function of wireless sensor network. And considering the tasks and robots are distributed in a great environment, we should take the position of the robots and the tasks into consider so that we can get optimal solution. Therefore we will propose an ant colony algorithm based multi-robot task allocation.

II. WIRELESS SENSOR NETOWRK

In this paper, we will design a multi-robot control system based on wireless sensors network. The system is composed of a control center, wireless gateway and wireless sensors. The structure of the wireless sensor network is shown in figure 1.

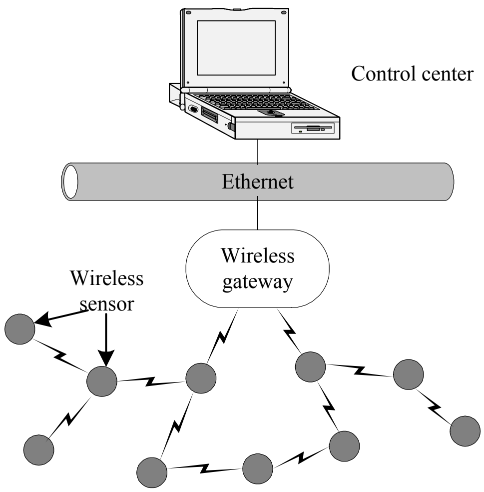

Figure 1. The structure of the control system

The control center manage the tasks and allocate tasks centralized, including task management module, task allocation module and task-issuing module. The task management module records the status information of the tasks and the information of the robots. The task allocation module allocates tasks according to the information of tasks and robots. The task-issuing module issues the task allocation solution and receives the answering information of the robot via the wireless sensors network.

The wireless gateway connects with the control center via the Ethernet. It can transit the wired signal from control center into wireless signal and send out to wireless sensors, and vice versa.

The wireless sensors can broadcast message to the robots, and receive the message from robots and send it to the control center by multi-hop relay. And also it can provide localization information to the robots.

III. MULTI-ROBOT COORDINATED CONTROL

A. Tasks and Robots Information Description

In this paper, the task of the robot is to transport some goods distributed in the environment from their initial place to the goal place. Therefore, the task is described with a four-triple

$$ta = \{tID, tP, tW, tR\}$$

where tID is the identification number of the task. tP is the place of the task, including initial place and goal place. tW is the weight of the task. tR are the robots allocated to process the task and it can be described with a chain table.

The robot can be described with a three-triple

$$r = \{rID, rC, rP\}$$

where rID is the identification number of the robot. rC is the working capacity of the robot, which can be expressed with the task weight the robot can process once. rP is the position of the robot.

Because the task weight is much greater than the working capacity of one robot, the robots will process the task by many times. Supposing the working capacity of robot r_i is rC_i and its current task is ta_j, the robot will inform the control center if it has just finished task transport once. Then the status of task ta_j will be updated. Its weight will given by

$$tW_j = tW_j - tC_i \tag{1}$$

If $tW_j \le 0$, it means that the task has been accomplished and the task will be written off in the control center.

B. The Task Allocation Policy Based on Efficiency Optimal

Because the tasks are distributed and the weight of the tasks is different, the processing time of the tasks is different. If the processing time of task ta_i is T_i and the maximum processing time of the tasks is $T_{\max}$, then the processing time of all the tasks should be $T_{\max}$. Supposing all the robots move with the same speed and all the tasks are independent with each other, the task processing time is related to the weight of the task, the initial and final place of the task, the number of the robots processing the task and the working capacity of the robots. If the weight of task ta_i is tW_i, the distance between the initial place and final place of the task is d_i and the robots processing ta_i is tR_i, the task processing time T_i is given by

$$T_i = 2\frac{tW_i}{\sum_{r \in tR_i} rC_i}\frac{d_i}{v} \tag{2}$$

where v is the moving speed of the robot.

In order to accomplish all tasks with the least time, we should minimize the maximum processing time $T_{\max}$, then the optimize target is $\min(T_{\max})$. In other words, we should optimize the task allocation solution.

C. Multi-Robot Task Allocation Algorithm Based on ACO

Ant colony algorithm (ACA), first introduced by Colorni[17,18], et al, was a new metaheuristic approach inspired by the foraging behavior of real ants. Many scholars have put their focus on using it to settle the hard combinatorial optimization problems, such as the traveling salesman problem

(TSP)[17,19,20], the quadratic assignment problem (QAP)[17,21], the graph coloring problem (GCP)[17,22], and so on. It has been proved that multi-robot task allocation and is a NP hard combinatorial optimization problem in which it was impossible to find an optimal solution without using an essentially enumerative algorithm, and the computational time increases exponentially with problem size. In this paper, we will apply ant colony algorithm in multi-robot task allocation. The algorithm is described as follow.

Step 1: Initialize maximum iterative time $\max i$ of the algorithm and set the current iterative time $nc = 0$. Create a $n \times m$ pheromone matrix p, where n is the number of task and m is the number of robot. Initialize the pheromone matrix $p(t,r) = p_0$. $p(t,r)$ is the pheromone strength between task t and robot r. Create an ant colony composed of na ants and n chain tables. Each chain table is used to store a group of robots. The chain table ct_i is used to store the robots allocated to process task t_i. Create a larger parameter ft to be the task processing time.

Step 2: Create an unallocated robot collection R and put all robots into R. Select an ant randomly in the ant colony to perform task allocation process; the ant will select a robot to allocate.

Step 3: Suppose that the ant has selected robot r, the ant will decide which task the robot will be assigned to perform. It select task t according to

$$t = \begin{cases} \arg\max\left\{[p(c,r)]^{\alpha}[\varsigma(c,r)]^{\beta}\right\}, if\ q \le q_0 (\exp lore) \\ S, otherwise (\exp loit) \end{cases} \quad (3)$$

where $\exp lore$ means exploring a new solution. $\exp loit$ means exploiting the existing knowledge, $p(c,r)$ means the pheromone strength between task c and robot r, $\varsigma(c,r)$ is a visibility heuristic function which is given by

$$\varsigma(c,r) = 1/d(c,r) \quad (4)$$

where $d(c,r)$ is the distance between robot r and the initial position of task c.

$\alpha(\alpha > 0)$ and $\beta(\beta > 0)$ are respectively the pheromone heuristic parameter and the visibility heuristic parameter, which are used to adjust the relative importance between pheromone and visibility. q is a random number distributed between [0,1]. $q_0(0 \le q_0 \le 1)$ is a parameter used to adjust the relative importance between exploring a new solution and exploiting the existing knowledge. S is a random number given by (5), means the probability that the ant select task t. In a word, if $q \le q_0$, select task according to (3); else select task according to (5)

$$t = [p(t,r)]^{\alpha}[\varsigma(t,r)]^{\beta} \Big/ \sum_{s \in T} [p(s,r)]^{\alpha}[\varsigma(s,r)]^{\beta} \quad (5)$$

where $s \in T$ means task s belongs to task collection T.

If the ant has selected task t, it will release some pheromone between task t and robot r. The pheromone strength between task t and robot r will be

$$p(t,r) = p(t,r) + p_{rel} \quad (6)$$

where p_{rel} is the pheromone strength released by the ant.

Store robot r in the chain table of task t.

In order to simulate the volatilization of the pheromone, the pheromone is updated while the searching the task allocation solution. The pheromone between robot and task is updated according to

$$p(r,v) = (1-\rho)p(r,v) + \rho p_0 \quad (7)$$

where $\rho(0 \le \rho \le 1)$ is a parameter simulating the volatilization of the pheromone.

Step 4: Delete robot r from R. If $R \ne \Phi$, select another robot in R, go to step 3; else, go to step 5.

Step 5: At this time, the robots stored in chain table ct_i are the robots allocated to perform task t_i. Calculate the finish time of each task and choose the maximum value $t_{\max}$ as the processing time of all the tasks.

If $t_{\max} < tf$, $ft = t_{\max}$. Record the current task allocation solution.

Step 6: $nc = nc + 1$. If $nc < \max i$, put all robots in R again. Select an ant randomly and clean each chain table, go to step 3; else, end the algorithm.

Then the current task allocation solution is the final optimal solution.

D. Multi-Robot Cooperated Task Processing Based on Wireless Sensors Network

To get optimal task allocation solution, the tasks are allocated by the control center centralized and then inform the robots the task allocation solution in this paper. The multi-robot task allocation process is shown in figure 2.

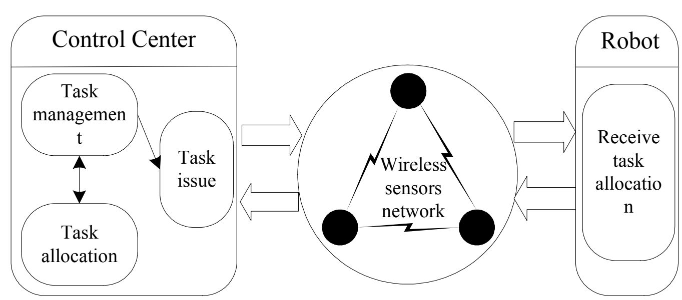

Figure 2. Multi-Robot task allocation process

The process is described as the following steps.

Step 1: Input the tasks information into control center manually. The task management module establishes one information archive for each task, including the task ID, task quality, initial position and final position of the task. And it also creates one chain table for each task used to store robots.

Step 2: The control center sends the position validation information out to the robots. The robots locate themselves in virtue of wireless sensors and feed their position information back to the control center. The localization method is described as follow.

Suppose that the coordinate of wireless sensor S_i is (x_i, y_i). S_i transmits wireless radio-frequency signal and ultrasonic wave signal at the same time. If the velocity of the two signals are c_r and c_u respectively, and the time that the two signal reaching robot are T_{ri} and T_{ui} respectively, then the distance between robot and S_i is given by

$$d_i = (T_{ui} - T_{ri})c_r c_u / (c_r - c_u) \quad (8)$$

If the distance between three sensors are d_i, d_j and d_k respectively, and the coordinate of the three sensors are $(x_i, y_i), (x_j, y_j)$ and (x_k, y_k), the location of the robot can be calculated by using three-edge measurement method.

Step 3: Task allocation module allocates task according to the proposed method and inform task-issuing module the task allocation solution.

Step 4: Task-issuing module broadcasts the robots the task allocation solution via the wireless sensor network.

Step 5: If robot receives the message, it sends a piece of confirm message to the control center. If the control center doesn't receive the confirm message, it will broadcast the solution again.

The robot will process the task once it receives the task allocation solution. And during task processing, it will locate itself in virtue of wireless sensors so that it can go from the initial place of the task to the final place of the task.

IV. EXPERIMENTS

To validate the proposed methods, a wireless sensor network composed of control center, wireless gateway and wireless sensors is designed and simulative experiments are done to simulate multi-robot cooperated transport containers piles on a dock. The wireless sensors are distributed in a relative large area to simulate a dock. The robots are shown in figure 3.

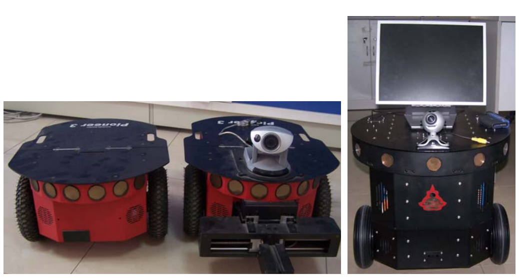

Figure 3. The robots

In this experiment, we have set the robots different working capacity and place them in different place, which are unknown to the control center. The working capacity and location of the robots are listed in table I.

TABLE I. THE WORKING CAPACITY AND LOCATION OF ROBOTS

Robot	Working capacity	Location
1	30	600，2300
2	25	1500，800
3	20	2400，100

Place two piles of containers in the environment. The three robots will transport the two piles of containers from their initial place to their final place. Input the containers' information into the control center manually, the control center allocate task according to the method mention above. The task information and the task allocation solution are listed in table II.

TABLE II. TASK INFORMATION AND TASK ALLOCATION SOLUTION

Container pile	Initial place	Final place	Weight	Solution
1	300，4000	3500，2000	300	1、3
2	3300，2000	600，3400	200	2

Table II shows that robot 1 and robots 3 are allocated to transport container pile 1. Robot 2 is assigned to transport container pile 2. Because the task allocation algorithm is related to the distance between robots' initial location and the initial place of the task, the task allocation solution also shown that the robots located themselves in virtue of the wireless sensors and feed the location information back to the control center. In the experiment, set the moving velocity of the robot to be 0.2m/s. The processing time of the two containers piles are 1237 second and 1354 second respectively. In other words, the robots have accomplished the tasks successfully. That means the robots located themselves during containers transporting. It proved that the robots had successfully accomplished the tasks by control of the wireless sensor network.

V. CONCLUSION

In this paper, a wireless sensor network is designed to control the robot to process tasks in a great environment coordinately. The wireless sensor network not only allocated tasks centralized, but provided localization information for the robots to help the robot localization. Experiments shown that the proposed approach can control the robots processing task in a great environment successfully.

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