

# Multi-Robot Multi-Task Allocation for Hospital Logistics

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**Abstract**— A number of materials are delivered inside a hospital, and a fleet of autonomous navigating mobile robots are applied to replace these heavy mobility works. To increase the efficiency of using multiple robots, more than one delivery tasks can be assigned to a robot instead of delivering only one package at a time. This multi-task allocation algorithm (MTA) is introduced in this paper and a simulator is developed to measure the performance of the algorithm. The simulator models the hospital environment and enables to compare the delivery productivity by changing the number of robot. It shows that the efficiency of MTA increases dramatically compared to the single task allocation when using the same number of robot.

**Keywords**— allocation, hospital, logistics, mobile, robot, task

## I. INTRODUCTION

Many delivery materials occur hospital-wide which includes blood samples, medicine, mail, linens and meals. Staffs and nurses are tired of turn-around long distance with tugging heavy materials. The walking distance for these workers reaches 10 km during their shift [1] and transportation tasks occur up to 195 hours a week. [2] Hospitals are now opening their places to mobile robots for helping their staffs for the delivery. A mobile robot has been introduced to replace the human workforce. [3] Companies such as Aethon and Swisslog have developed a mobile robot for hospital logistics. [4] Robots work 24/7 and are able to navigate autonomously anywhere inside a hospital without artificial landmark avoiding obstacles where people are coexisting. A research shows that 6 robots can save 2.8 full-time equivalent employees. [5, 6] Nowadays, more hospitals are opening their places for the robot courier [7] such as UCSF medical center in which 25 Tugs are already in service. [8]

The delivery robot moves according to the following sequence: i) starting from the base, ii) arriving at the pick-up position, iii) moving to the drop-off position, and iv) returning to the base. Sometimes the base and the pick-up position can be at the same position. Available robots are assigned for the delivery task. However, even though all robots are out for delivery, the delivery request occurs continuously. If there are no optimal allocation algorithm, a robot can perform only one task at a time. In this case, if all robots are busy, the later requested delivery should wait until a robot has finished its task and become available. This method is trivial and is not productive for using multiple robots. This method is called single-task allocation (STA). Therefore, we introduce a multi-

task allocation (MTA) method to increase the productivity. This method allocates more than one task to a robot. To assign multiple tasks to already delivering robot, it has to consider the travel distance, remaining battery and maximum load capacity. Then, it selects an appropriate robot (currently delivering robot) to assign multiple tasks. It also has the associating procedure of re-planning the path with current task and newly assigned task. This method will shorten the waiting time of the pick-up position and increase the overall efficiency. To test the performance of STA and MTA algorithms, we developed a simulator implementing the hospital environment and the robot. When the simulator runs, the task allocator assigns a robot to perform a delivery task, and the robot moves to delivery positions inside the map by autonomously planning the path.

Given the scale and map of the hospital environment and the estimated schedule of delivery, the management of the hospital can decide how many robots to deploy at the hospital to meet the desired delivery performance. This simulator can also be used to estimate this performance.

## II. EXPERIMENTS

### A. Task Allocation Algorithm

A delivery task is consisted of a pick-up position and a drop-off position. Each positions are, in general, point-of-interest. (POI) When a delivery request occurs, a task allocator in the control server selects an appropriate robot for the request. Normally, a standby robot in the base station is selected for the delivery. However, since the delivery request occurs continuously, there can be a situation that there is no more standby robots at the base. In this case, the task allocator should decide whether to wait until there is an available robot, or to select currently working robot and add one more task. The former is single-task allocation (STA) and the latter is multi-task allocation (MTA). In MTA, the task allocator should also replan the path of the selected robot to minimize the travel distance. The selected robot has its current task's POIs and newly added POIs to visit. The task allocator has to associate both POIs to find optimal path. In this paper, we only considered the distance to find optimal path. Battery and capacity will be considered in the future work.

In MTA, the robot receiving new task is selected by exhaustively calculating paths of all robots from their current positions to the newly added pick-up positions. (Fig.1) This first order searched path is derived from calculating the shortest

distance from current pose, to currently heading POI (Fig.1 (c)) or to newly added pick-up POI. (Fig.1 (d)) The shortest path is selected from the two. Then, it calculate distance again vice versa, that is, from the selected one to the other one. The robot which gives the shortest distance is finally selected to add new task. Then, again, by exhaustive searching the shortest path of the selected robot is done by associating currently remaining task's POIs and newly added task's POIs. The path should follow the constraints that drop-off position cannot go ahead of pick-up position.

This way MTA selects a robot which delivers two tasks. To test the performance of STA and MTA, a simulator is designed. It models hospital environment, robot and the schedule of frequent delivery tasks.

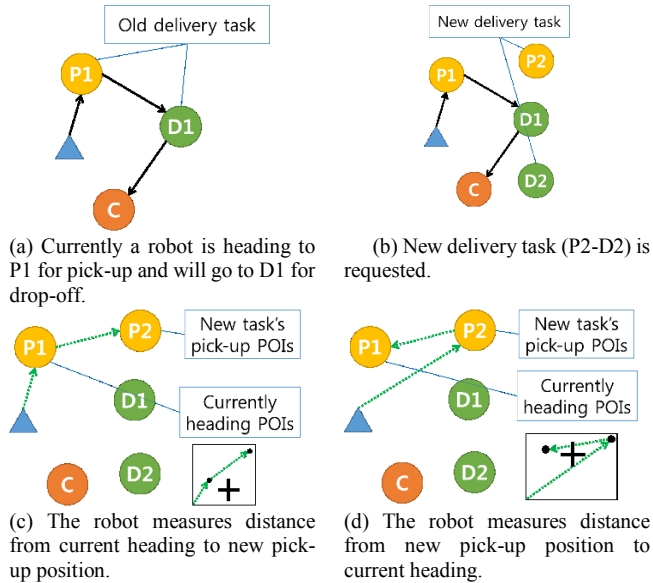


**Figure 1.** The method of finding path to select a robot for multi-task allocation.

## B. Experimental setup

To evaluate the delivery performance of robots, a simulator is developed to test various condition of using multiple robots for hospital logistics. The simulator is composed of the parameter setup, task scheduler, core, and data analyser as in Fig.2. [9] The task scheduler is a list of user-defined task schedule including type of goods, time period, and positions of pick-up and drop-off. The environmental parameters are defined in the parameter setup module which affects the simulation of the core. The core is where robot runs on-line and invokes the delivery request according to the task scheduler. The task allocator inside a core assigns the newly received task to the robots while considering the constraints. The data analyser shows the result of the delivery tasks including waiting time, total delivery time, and also the number of finished tasks of each robot.

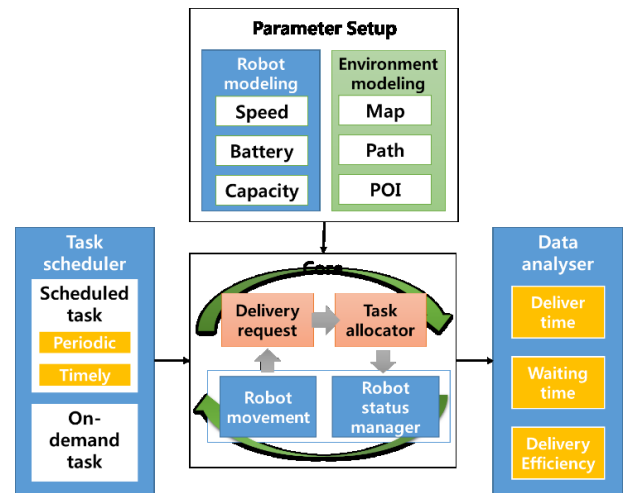


**Figure 2.** Framework of the hospital logistics simulator. The simulator is consisted of the Parameter Setup, Task Scheduler, Core and Data Analyser modules. After setting the parameters and scheduling delivery tasks, the core runs abstracted 9 hours in which delivery requests are called and robots are moved with their velocity. Once simulation is finished, the user can obtain the simulated performance result in the data analyser.

## C. Simulated result

10 robots are used in the map of 60m \* 70m with 8 delivery positions as in Fig. 3. The maximum number of delivery task a robot can accept is 2. The simulation runs for abstracted 9 hours and the frequent on-demand task of each POI for testing is scheduled as table 1. As an example, the delivery request from 7<sup>th</sup> POI to 1<sup>st</sup> POI is called every 5 minutes. The duration from the base station to 7<sup>th</sup> POI is about 8 min with the velocity of 1m/s.

The performance of STA and MTA algorithms are tested in the simulator. The performance is compared by the allocation time, waiting time, and total delivery time. The allocation time is the time between a delivery request and assignment of a robot. In STA, when all robots are currently conducting a task when there is a new delivery request, the assignment of robot is delayed until a robot finishes its task. The waiting time is the time from requested for delivery time until a robot comes at the POI to pick-up a package. The total delivery time is the time between pick-up and drop-off.

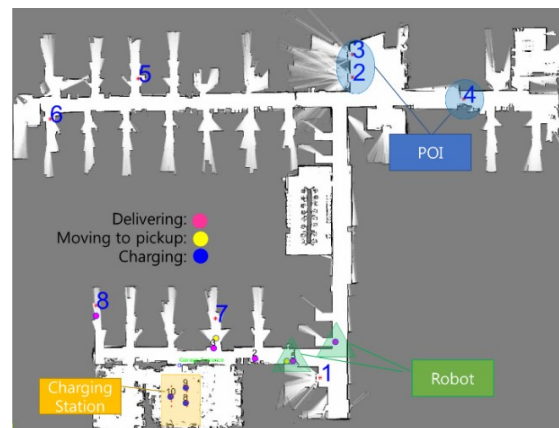


**Figure 3.** Simulation image. There are 8 POIs and 10 robots on the 60m \* 70m map.

**TABLE 1.** THE SCHEDULE OF DELIVERY

| Frequency | From | To |
|-----------|------|----|
| 5 min     | 7    | 1  |
| 13 min    | 7    | 8  |
| 30 min    | 7    | 5  |
| 54min     | 5    | 1  |
| 55min     | 8    | 6  |
| 60min     | 4    | 7  |

The result of single-task allocation (STA) and multi-task allocation (MTA) can be seen in Fig.4. The blue line is STA, and the red line is MTA. The x axis of the graph is the sequentially numbered ID of the delivery task and the y axis is the waiting time in minutes. The waiting time for a robot to be assigned of STA is increasing as time passes since all other robots are busy conducting already assigned delivery task as in Fig.4(a). Similarly, the waiting time until a robot arrives for pick-up after a delivery call increases for STA while MTA remain relatively short as in Fig.3(b).

The overall result of the allocation can be seen in Table 2. The number of finished task of MTA is larger than STA in 104.67% in a given simulation time and the waiting time of MTA decreased dramatically as 32.96%.

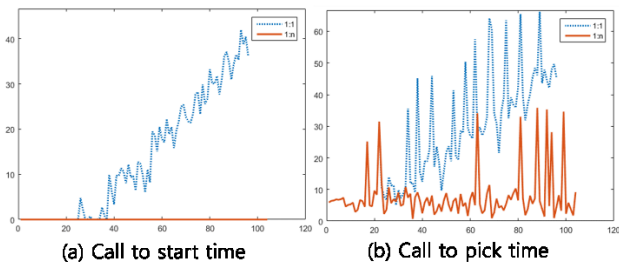


**Figure 4.** The x-axis is sequentially numbered ID of the delivery task, and the y-axis is the time. Blue line is single-task allocation, and the red line is multi-task allocation. The consumed time increases as time passes for single-task allocation while multi-task allocation remain relatively short.

**TABLE 2.** THE RESULT OF ASSIGNED TASKS

|               | STA<br>(A) | MTA<br>(B) | Result<br>(B/A) |
|---------------|------------|------------|-----------------|
| Finished task | 171        | 179        | 104.67%         |
| Waiting time  | 31.7min    | 10.4min    | 32.96%          |

### III. CONCLUSION

Many various materials are delivered inside a hospital, and a fleet of autonomous navigating mobile robots are introduced to replace such heavy mobility works. Instead of using the robot for delivering one package at a time, (STA) more than one tasks can be assigned to a robot (MTA) to increase the efficiency of using multiple robot. Therefore, a task allocation algorithm is introduced to enable multi-robot-multi-task allocation. The performance is tested in the simulator which models hospital environment. And it shows that the efficiency of using the same number of robot increases dramatically when the multi-task allocation algorithm is applied.

Also, the management group of a hospital wants to know how many robots are required in their hospital. This hospital logistics simulator enables to simulate robots in nearly realistic environment and shows the approximated performance of robots about waiting, delivering time which helps decision of purchasing robots.

In this experiment, we only considered the distance to select an appropriate robot. Battery and capacity will be considered in the future work.

### ACKNOWLEDGMENT

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