On the Effect of Carrier Robot's Capacity and Speed Towards Task Delivery in Smart Factory

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***Abstract*—Pickup and delivery is an activity that always going on within smart factories. In this paper, a pickup and delivery task allocation system integrated with edge computing is proposed for a smart factory. The focus is on the analysis of the effect of using carrier robots with varying capacity and speed for pickup and delivery task execution in a smart factory. The simulation results show that using carrier robots with small capacity and high travel speed can produced better task execution performance than using carrier robots with large capacity and low travel speed.**

***Index Terms*—Carrier robot, pickup and delivery, smart factory, edge computing.**

I. Introduction

One of many activities in smart factories is pickup and delivery of goods inside the smart factory. Automating pickup and delivery processes for smart factories can offer great benefits, such as reducing labor costs and human error [1]. Automatic operation by using carrier robots (CRs) is a preferable to increase the effectiveness and efficiency of pickup and delivery operations.

The main focus of this paper is analyzing the effect of the CR's load capacity and travel speed towards performing pickup and delivery tasks. Two types of CR, each with different travel speed and load capacity, are introduced and used for the simulation to provide perspective in terms of successful task delivery and traveled distance for each robot.

II. Proposed System in Smart Factory

The architecture of the proposed system is illustrated in Fig. 1. It mainly consists of the main server, edge servers, and CRs. The new task request is first passed through the main server. The main server then will be responsible to select the best-suited edge server for the new task. The edge servers then determine which CR will execute the latest new task and how the chosen CR's travel route is changed to accommodate the new task's pickup and delivery. All CRs stand by, start moving from, and return to the robot pool. During the travel, the CR may receive a new task, which then will alter the route.

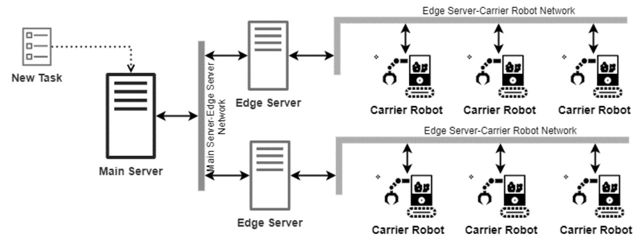


Fig. 1. Illustration of the proposed system architecture in smart factory.

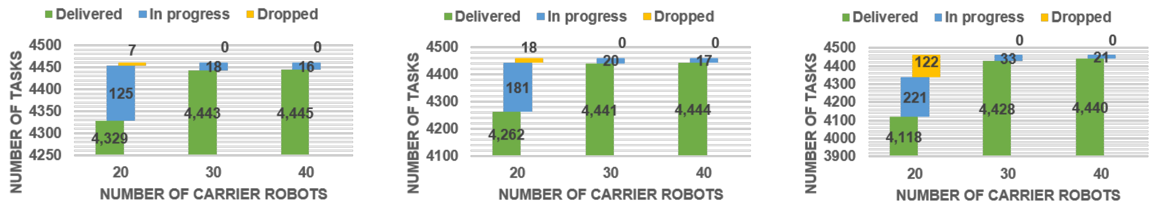
The problem of matching a new task with a CR can be modeled as a Vehicle Routing Problem. Let $S = \{s_1, s_2, \ldots, s_{\mathbf{S}}\}$ be a set of $\mathbf{S} > 0$ working stations in the smart factory and $R = \{r_1, r_2, \ldots, r_{\mathbf{R}}\}$ be a set of $\mathbf{R}$ pickup and delivery tasks of the CR. The objective function that must be solved to determine the best travel route for a CR can be formulated as follows

$$\begin{aligned} \min \quad & \sum_{i\in S}\sum_{j\in S} d_{i,j}\, x_{i,j}, \\ \text{s.t.} \quad & \sum_{i\in S} x_{i,j} \le 1, \quad \forall j \in S, \\ & \sum_{j\in S} x_{i,j} \le 1, \quad \forall i \in S, \\ & \dot{t}_r < \check{t}_r \le \ddot{t}_r, \quad \forall r \in R, \\ & \hat{t}_r > \check{t}_r, \quad \forall r \in R, \\ & \Upsilon_r \le \tilde{\Upsilon}, \quad \forall r \in R, \\ & L_i \le \tilde{L}, \quad \forall i \in S, \end{aligned} \tag{1}$$

where $d_{i,j}$ denotes the travel distance from station i to station j; $x_{i,j}$ is a binary variable that is equal to 1 if the route contains direct travel from station i to station j or 0 if there is no such direct travel; $\dot{t}_r$, $\check{t}_r$, $\ddot{t}_r$, and $\hat{t}_r$ denote the assignment time, the pickup time, the pickup deadline, and the delivery time of task r; Υ_r and $\tilde{\Upsilon}$ denote the detour ratio of task r and the maximum detour ratio; L_i and $\tilde{L}$ denote the CR's load weight at working station i and the CR's load capacity. Because the problem falls into the combinatorial optimization category, Binary Particle Swarm Optimization (BPSO) Algorithm is used to minimize the objective function. In this paper, the BPSO will not be further explained, as it has been well explained in other papers such as in [2]–[4].

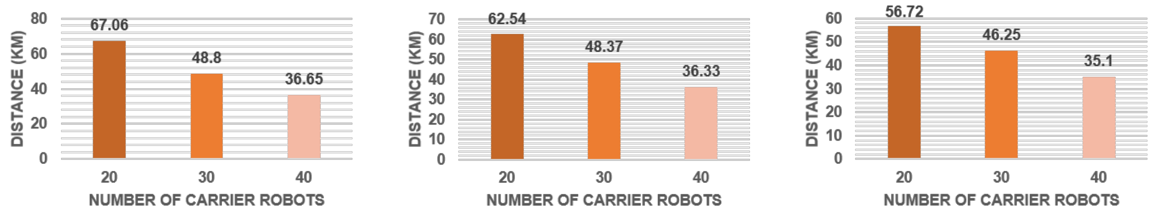
III. Simulation Results

The presented simulation results were focused on the impact of CR's capacity and speed on the pickup and delivery task execution in the smart factory settings. The simulation parameters are shown in Table I. Two types of CR were used in



(a) (b) (c)

Fig. 2. The tasks' statuses within twelve hours of operation in (a) Case 1, (b) Case 2, and (c) Case 3.



(a) (b) (c)

Fig. 3. The average total traveled distance for a CR after twelve hours of operation in (a) Case 1, (b) Case 2, and (c) Case 3.

TABLE I
PARAMETERS IN SIMULATION.

Parameter	Value
Number of working stations	10
Number of edge servers	5
Maximum pick up waiting duration	600 s
Maximum task delivery detour ratio	1.5
CR Type A's travel speed	2 m/s
CR Type A's load capacity	100 units
CR Type B's travel speed	1.5 m/s
CR Type B's load capacity	200 units
Simulated duration of smart factory operation	43200 s (12 h)
Probability of new task occurrence in each second	10 %
Factory area size	200 m × 100 m

simulations: Type A and Type B, each with different capacity and travel speed. Three cases were considered for performance analysis: Case 1: using CR Type A only, Case 2: using CR Type A and Type B with same number, and Case 3: using CR Type B only.

The simulation results on the delivery status of all tasks are shown in Fig. 2. The first case gave the best performance, with the most successful task deliveries and the least number of dropped tasks. The CR Type A had a smaller capacity but higher speed than CR Type B, allowing CRs to move swiftly in-between stations. The simulation results on the average total traveled distance by each CR is shown in Fig. 3. The third case produced a relatively shorter average total traveled distance, compared with the other cases. These results were expected because CR Type B can handle more tasks concurrently with its larger capacity. Considering also results from Fig. 2, using thirty CR Type As for smart factory is shown to be the best option.

IV. Conclusion and Future Works

From the simulation results, the proposed system deploying CRs with small capacity but high speed showed better performance in task delivery when not many new tasks are coming in a short period of time. Even with small capacity, if CRs have high speed, they can quickly deliver the tasks assigned to them and be ready for new tasks. Future works include exploring other ways of balancing task allocation over edge servers and adding more metrics to determine service load of edge server.

Acknowledgment

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (2019R1I1A1A01063895), and the Ministry of Science and ICT of Korea, under the Grand Information Technology Research Center Support Program (IITP-2020-2020-0-01612) supervised by the Institute for Information & Communications Technology Planning & Evaluation (IITP).

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