Smart Technologies for Coexistence between Humans and Robots in Buildings

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1. Introduction

In Japan, to cope with the decreasing working-age population due to the declining birthrate and aging population, robots that work autonomously instead of humans are being considered. Mitsubishi Electric Corporation has been developing technologies for using robots in buildings. If multiple robots move in a building, they may pass each other in a narrow passage or get on and off an elevator. If the robots are large, they may become deadlocked and come to a standstill. Furthermore, if robots use elevators during commuting hours or other busy periods, they may hinder human movement. This paper describes a robot and building facility cooperative control technology[(1)(2)] being developed by Mitsubishi Electric to solve such problems.

2. Robot and Building Facility Cooperative Control Technology

2.1 Outline

The robot and building facility cooperative control technology allows robots to travel safely in buildings and thus work more efficiently by using information on the positions of humans and robots in the buildings, operation data of elevators and other equipment, and building maps. Figure 1 shows the structure of the robotic control and guidance system in a building using this technology. The system consists of the following functions: (1) a function for managing dynamic map data in a building, which manages the positions of humans and robots and the operation statuses of elevators and other equipment in real time, (2) a route searching function that calculates the paths that the robots can travel along in the building, (3) a behavior planning function that creates behavior plans for robots to maximize their operation efficiency in the building, (4) a guidance and control function that informs the robots of travel paths and gives them travel instructions, and (5) an infrastructure-linked travel control function by which the robots select an appropriate speed and path based on the indoor travel environment using information (map data of the travel paths) provided by the control and guidance system.

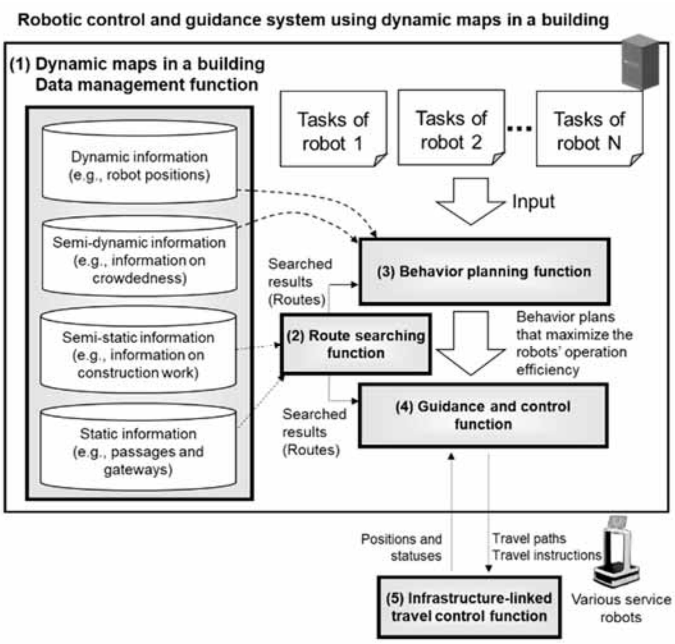

Fig. 1 Robotic control and guidance system

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2.2 Robotic control and guidance system using maps in a building

This section describes the five functions of the robotic control and guidance system described in Section 2.1.

2.2.1 Function for managing dynamic map data in a building

Dynamic map data in a building is indoor map data developed independently by Mitsubishi Electric. In the data management method, the map data is classified into four levels based on the data update cycle: static, semi-static, semi-dynamic, and dynamic information (Fig. 1). Static information includes information on fixed objects (e.g., wall surfaces, floor surfaces, elevators, and gateways) in the building; semi-static information includes information in units of days and hours (e.g., information on construction work and elevator maintenance); semi-dynamic information includes information in units of hours and minutes (e.g., information on crowdedness and cleaning); and dynamic information includes information in units of minutes and seconds (e.g., information on the positions of robots and humans and elevator operation). In addition, the contents and format of dynamic map data in a building conform to the "Data specifications of indoor geospatial information expressed for each floor (draft)" issued by the Geospatial Information Authority of Japan, which the Japanese Ministry of Land, Infrastructure, Transport and Tourism is using in a project for turning digital indoor maps into an open database.(3) Therefore, digital indoor map data on public facilities can also be used.

2.2.2 Route searching function for robots in a building

This function uses network data (links and nodes) included in static information of the dynamic map data in a building as shown in Fig. 2 to search for a route to the node closest to the specified destination. Passable direction(s) and distances are set to each link and Dijkstra's algorithm is used to search for a route with the shortest travel distance to the destination. If some links cannot be used due to construction work and elevator maintenance for which information is included in the semi-static information of the dynamic map data in the building, then the links are excluded from the search targets. This enables passable routes to be calculated for each situation. The searched results are used by the behavior planning function (Section 2.2.3) and by the guidance and control function (Section 2.2.4).

2.2.3 Function for planning behaviors of robots in a building

To provide a comfortable travel space for both robots and humans in a building, it is necessary to maximize the total operation efficiency of the robots without hindering the movement of humans. To realize this, when planning the behavior of each robot, time periods during which elevators get crowded are estimated based on statistical information on elevator use and constraints are determined. Examples of such constraints include "the robots must not use elevators at crowded times" or "the maximum number of elevators used by robots during crowded times shall be limited." For example, as shown in Fig. 3, during a time period when elevators get crowded, the robots only perform charging or tasks. By planning robot behavior and giving them instructions in this way, it is possible to keep the travel environment comfortable for both humans and robots while maximizing the number of tasks that the robots perform.

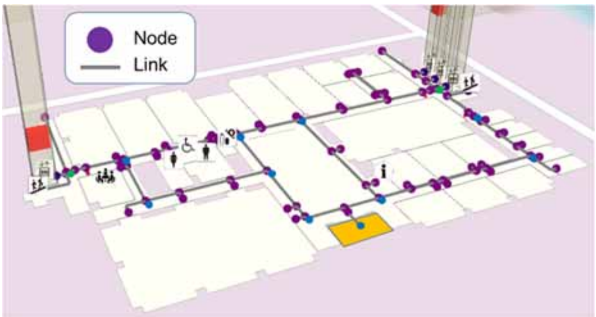

Fig. 2 Example network data of dynamic map in a building

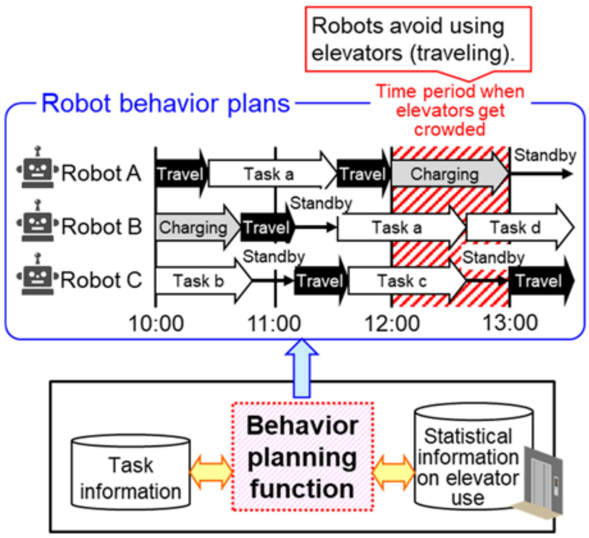

Fig. 3 Planning function of robot behavior

2.2.4 Function for robot guidance and navigation in a building

A building may have narrow passages or areas where multiple robots cannot pass at the same time (collision path in Fig. 4). Even if a constraint is determined, for example, by limiting the number of robots that can travel on the collision path at the same time to one using the behavior planning function, the travel times of robots may be disrupted by having to wait for elevators. Therefore, there is no guarantee that the robot can travel on the collision path at the scheduled times. Consequently, this guidance and control function obtains information on the robot positions at intervals of approximately one second: when two or more robots are expected to enter a collision path at the same time, the function stops one of the robots before it enters the path and gives the other priority to use the path, realizing smooth indoor robot travel.

2.2.5 Function for a corporative navigation between mobile robots and building platforms

Our guidance system publishes not only coordinates of points (nodes) but also width, direction and traffic rules and then robots can control adaptively in building platforms by restricting a navigation route search area by situations and improving localization accuracies by geometries. As a result, robots enable to pass through elevators' narrow doors safely (Fig.5).

2.3 Technologies for the safety and security of robot travel

This section describes technologies that support the safety and security of the robotic control and guidance system.

2.3.1 Indoor positioning using surveillance cameras

When multiple robots co-exist, it is necessary to prevent them from colliding with one another in a passage or elevator. To ensure this, Mitsubishi Electric has developed an indoor positioning technology in which surveillance cameras in the building are used to recognize the tags attached on robots, and the distance from the cameras to the tags and orientations are calculated with high accuracy in real time. This technology can identify a robot by reading its ID tag, and can also measure its position. An experiment using Mitsubishi Electric's MELOOK3 NC-7620 surveillance camera has confirmed that this indoor positioning technology can detect the positions of robots in an indoor area measuring 3.0 m long by 5.0 m wide by 2.7 m high accurately and quickly. The average position error is 15 cm or less and the positioning time is less than 100 ms (Fig. 6).

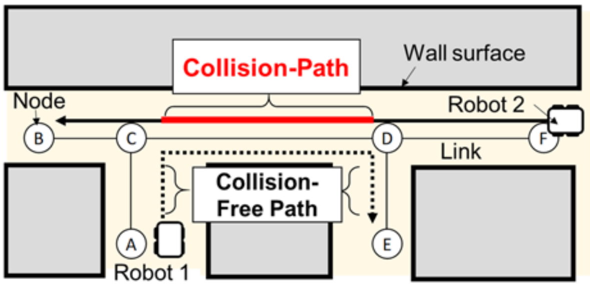

Fig. 4 Area where robots cannot pass at the same time

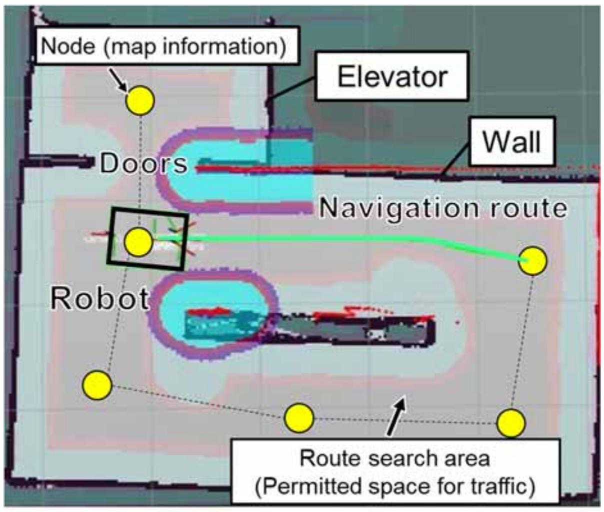

Fig. 5 Searching for a robot's navigation route using map information

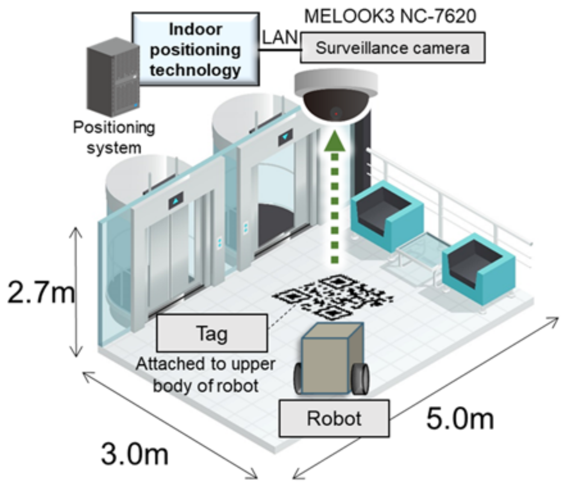

Fig. 6 Indoor positioning technology for robots using surveillance cameras

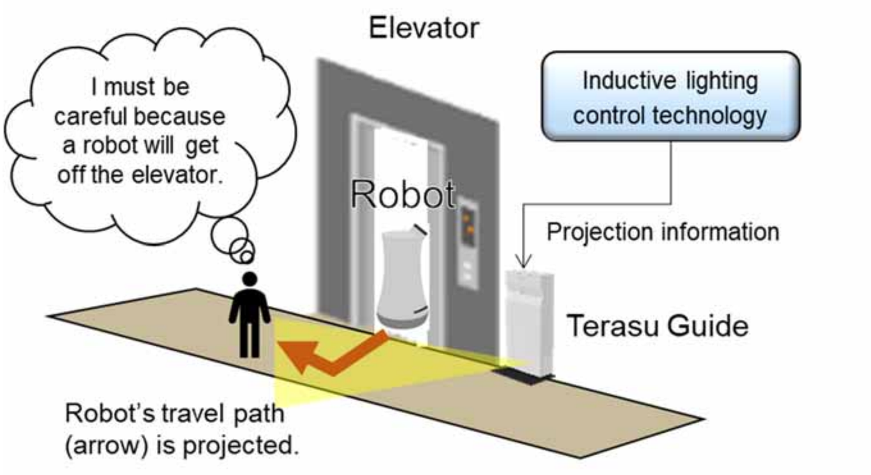

Fig. 7 Example of using inductive lighting control technology

2.3.2 Inductive lighting control for safe travel

Humans and robots must be able to travel safely when coexisting in a space. For example, when a robot gets off an elevator, it must not collide with someone entering the elevator. Mitsubishi Electric has been developing "Terasu Guide", a projector-based animation lightning system, and will develop an inductive lighting control technology using Terasu Guide to avoid collision and ensure safe travel by humans and robots. In the inductive lighting control technology, an image of a robot getting off an elevator is projected onto the floor or wall in front of an elevator (Fig. 7). The technology uses robot position information and scheduled travel paths to determine in advance which floor the robot will get off and at what time, and projects the image at the appropriate time. This will give users of facilities in a building intuitive and easy-to-understand information to help them travel safely and easily.

3. Conclusion

This paper described a robot and building facility cooperative control technology being developed, focusing on the control and guidance system for robots in a building and elemental technologies for safe operation of the system. Currently, Mitsubishi Electric is conducting a demonstration experiment using these technologies (Fig. 8). We will keep improving the technologies and create new solutions to realize a sustainable society that offers safety, security, labor-saving, automation, and higher productivity.

Fig. 8 Proof of concept

References

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(3) Japanese Ministry of Land, Infrastructure, Transport and Tourism "Project for Turning Digital Indoor Maps into an Open Database"
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