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Development of mobile robot navigation system using simplified map based on place recognition

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Abstract: This paper introduces a mobile robot navigation system using simplified hybrid maps based on occupancy grid maps of important places and relationships among them. In order to achieve autonomous navigation with the hybrid maps, additional information, such as waypoints in important places with occupancy grid maps, are learned in SLAM process. Also, navigation system based on state transition between inside and outside of the important places is proposed. Finally, experimental results with actual robot systems in indoor environments are shown.

Keywords: Mobile robot navigation, Hybrid map, Position estimation

1 INTRODUCTION

Recently, various kinds of robots, such as cleaning robots, have been available in human living environments. In order to perform mobile robot navigation, environmental maps for robots are needed. Generally, most of studies for robot navigation use detailed occupancy grid maps representing all the environments that the mobile robots will move[1]. However, such global metric maps based on occupancy grids are not necessarily required for the purpose of navigation. At least, humans do not need such grid maps for navigation. Then, a number of navigation approaches consider using simple maps. Especially, hybrid maps that combine metric and topological maps have been widely proposed[2]. This study assumes the hybrid maps with geometrical relations between important places via straight lines are enough for representing the simple environments that consist of straight lines such as corridors. Then, this study aims to achieve autonomous navigation of the mobile robot using the hybrid maps at indoor environment.

2 SIMPLIFICATION OF THE MAP

2.1 Hybrid map

The robot's navigation in this study is performed using a hybrid environmental map as shown in Fig.1. In the hybrid map, occupancy grid maps are generated using FastSLAM[3] at important places with complicated shapes like crossing points among corridors. On the other hand, at the places with simpler shapes, such as corridors, detailed maps are not generated and only geometrical relationships between important places are learned. Then, the map representation does not lose necessary global relationships among important places as maps for robot navigation. In order for the robot to learn the map, we previously proposed a novel SLAM algorithm based on acquisition and matching of images in each important place[4]. Also, integration of occupancy grid maps in revisit places and etc. was added to the proposed SLAM algorithm. As the results

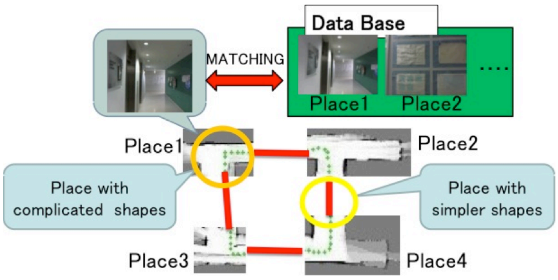


Fig.1 Outline of the proposed SLAM and hybrid map

of the proposed SLAM algorithm, exact geometrical relationships between important places are required. In other words, the robot has to judge whether the important place is visited for the first time or not in the SLAM process. Then, geometrical relationships between the place and the other places must be obtained. In order to recognize revisit or not, images are acquired at a fixed intervals in the important places and SURF features of the images are stored in databases. And, image features newly acquired in each place are compared with image features stored in the databases. According to matching results, "new" or "revisit" is recognized. Thus, the geometrical relationship between important places is recognized. In this study, two cameras are attached to the robot around the height of human's eyes (about 160 cm) in order to capture images. Cameras are set to right and left directions. This is because we can see specific information of each place, such as room numbers, information maps, etc. on walls or doors around the height of human eyes. These are easy to extract as image features and effective for image matching. The hybrid map is generated by the above method.

2.2 Information acquisition for navigation

The hybrid map simply expresses relationships among important places and occupancy grid maps of each important place. In order to perform autonomous mobile robot navigation with this map, additional information is required. For example, how to move in the important places should be considered. When the robot enters in the important places, robot positions and orientations must be accurately estimated in the coordinate system of each occupancy grid map. Waypoints in the each occupancy grid map are also required for going to the other place. Just learning relationships among important places are not enough for navigation because distances among places are also required for actual navigation. Then, in order to use the proposed hybrid map for navigation, the robot acquires the following information and adds the information to the hybrid map while map generation process with the proposed SLAM algorithm.

A) **Waypoints**: A starting point and a terminal point based on geometrical relationships among places, and relay points in the grid maps are used as waypoints for navigation. These points are called bridge points as shown in Fig.2. Relay points are defined as the middle waypoints between bridge points. The robot moves toward a bridge point via a relay point first in each place. A relay point is set in a position where the robot changed its heading 70 degrees in each place during map learning process.
B) **Gate**: Gates in each important place are straight lines for judging moving out from the place. The lines are calculated from the LRF scan data on bridge points.
C) **Distance between places**: It can be roughly calculated by odometry while map learning process.
D) **Acquisition positions of database images**: Images stored in database are mentioned in Chapter 2.1. Position of the robot in each place is estimated according to acquisition positions of database images.

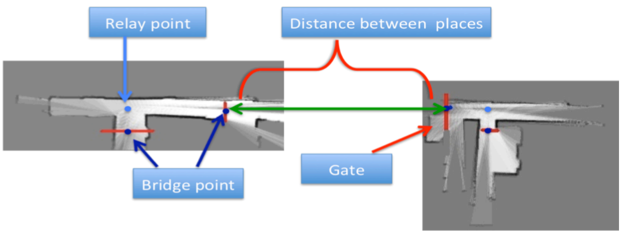


Fig.2 Information acquisition for robot navigation

3 NAVIGATION SYSTEM

In this chapter, navigation system using the hybrid map is explained. In order to perform navigation using the hybrid map, it is necessary to change localization and moving methods according to robot conditions. In the navigation system, robot conditions based on places are divided into three states: Inside, Outside A and Outside B. Details of the navigation system are explained as follows. Finally, the configuration of the system is shown.

3.1 Robot's state transition

The definition of three states in a navigation system is shown below. State transition diagram is shown in Fig. 3.

Inside: The robot is in a place under localization.

Outside A: The robot is out from a place through a gate. Its movement distance from the gate is less than distances between the last place and next places.

Outside B: Movement distance of the robot from the previous gate exceeds distances between the last place and next places before localization in a next place.

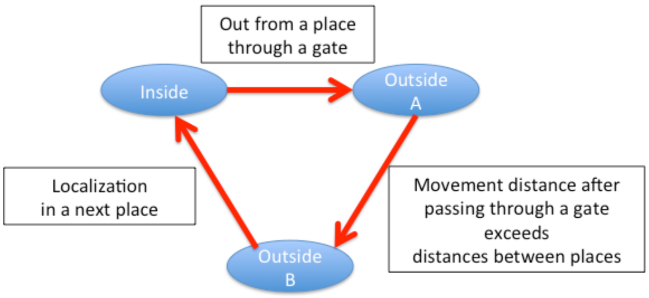


Fig.3 State transition diagram

3.2. Localization

Localization in three states is described below.

Inside: Localization is performed with particle filter using scan data of LRF and the grid map of each place.

Outside A: In this study, courses between places are assumed as corridors. First, position relationships between the robot and gates are calculated, when a robot state has just transited from Inside to Outside A. Coordinate system after transition to Outside A is defined according to relationships between the robot and the gate (Fig. 4). And, navigation along wall is performed. Moving distances along walls are also calculated from base information.

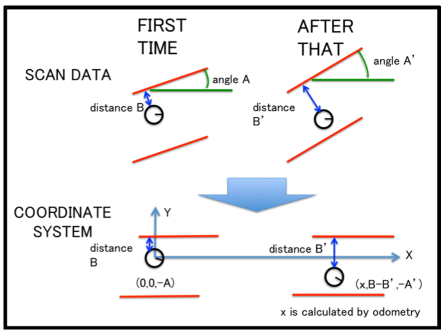


Fig4. Wall following method

Outside B: When a moving distance along walls exceeds distances between places memorized in the hybrid map, a state of the robot transits to Outside B. In this state, there are possibilities that the robot is in next places. Then, recognition of a place number and accurate localization in the place should be performed in this state. First, the rough self-position of the robot in the place is estimated by image matching with database images of places stored in the hybrid map. Next, the accurate self-position of the robot in the place is estimated by ICP matching with the grid map of the place. Details of this process are explained below. As described above, rough position estimation based on image matching is performed. Since images in the robot are captured in short sampling rate, successive captured images match same one of database images. In that case, an image with the highest voting rate can be regarded as the most similar image with one of database images. It is considered that the position of the robot is the closest to the acquisition position of database image. Then, the acquisition position of database image is exploited as the position, where the image with the highest voting rate is captured, as shown in Fig.5. In addition, recognition of the place number is also achieved from image matching. However, this position estimation is too rough to control the robot. So, accurate position estimation based on the scan data of LRF and a grid map is also performed. ICP matching[5] between the grid map and the scan data of LRF is performed. Rough position estimation results based on image matching are used as initial positions of ICP matching. The accurate self-position of the robot in the place is estimated from this matching. Although several images are saved in database as representing the places in the hybrid map, the first database image matched with one of successive captured images is only used for position estimation in each place. When the accurate self-position of the robot in the place is estimated, the state transits from Outside B to Inside. Image matching method in this position estimation is similar with the method of recognition of relationships between places for the hybrid map generation[4] except the followings.

Step2. All feature points in captured images from two cameras of the robot are not saved in a database. If features extracted in one image are less than 20, the image is deleted as out of matching.

Step3. Two votes are given for the image when Euclid distance between features is the smallest in order to find the nearest image with the corresponding database image. In this voting, two votes are needed for compatibility with calculation of the voting rate.

Step4. The images with more than 10% share of the voting rate in the databases are regarded as candidates of matching images.

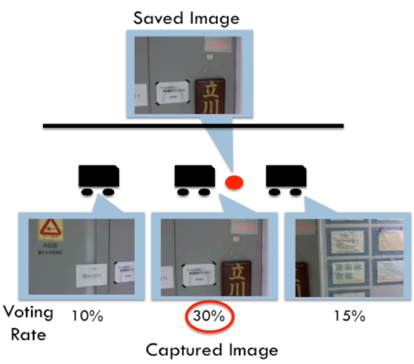


Fig.5 Image matching in Outside B

3.3. Navigation

A destination place number, a current place number and a rough self-position of the robot in the current place are given as initial information. Then, autonomous movement of the robot is carried out from the current place to the destination place. First, global path planning is performed using relationships of places. The shortest path is calculated by the Dijkstra method from the initial information. Path planning includes places transition from the current place to the destination place. Then, the robot moves according to the determined path. In navigation, the same movement is performed in Outside A and Outside B. Movement methods in Inside and Outside (including Outside A and Outside B) are shown below. The configuration of the navigation system actually used in this study is shown in Fig. 6.

Inside: First, the robot moves to a relay point in each place. Next, the robot moves toward a bridge point connected to the next place.

Outside: The robot keeps moving along a wall.

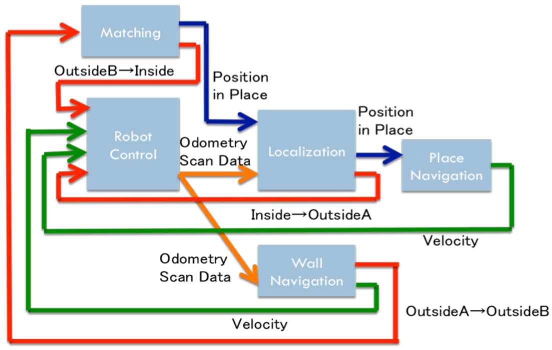


Fig.6 Navigation system

4 EXPERIMENT

4.1 Experiment setup

In this study, the mobile robot carries two cameras (Logicool® HD Pro Webcam C910) (Fig.7(b)) around the height of human's eyes and one LRF (HOKUYO electrical machinery UTM-30LX) (Fig.7(c)) ahead of the robot as shown in Fig.7(a). The experimental environment is one floor of university buildings (Fig.8). In this study, four corners or intersections are defined as important places in a hybrid map by a human operator before map learning. Also, in advance, the robot moved manually by a controller and the hybrid map was generated.

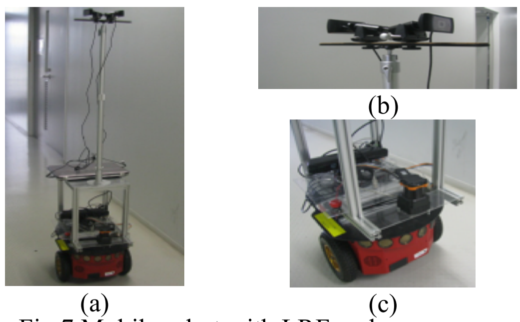


Fig.7 Mobile robot with LRF and camera

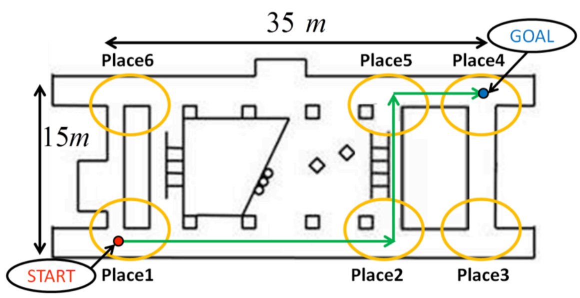


Fig.8 Experimental environment

4.2 Experiment method

In this experiment, it was tested whether autonomous navigation of the mobile robot could be actually achieved using the hybrid map. Followings are given to the robot in advance as initial information.

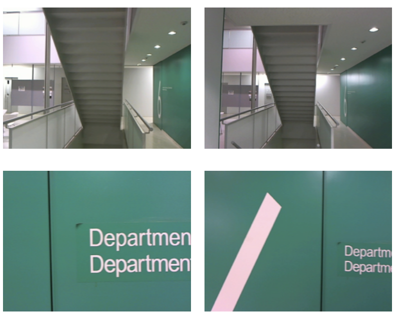
1) Initial place number
2) Rough initial position of the robot in the current place
3) Destination place number

After ICP matching based on the rough position to estimate for an exact position in the initial place, the robot starts movement. Each parameter setup is as follows. In localization with the particle filter, the number of particle was set to 30. In ICP algorithm, the maximum loop count was set to 500 times. Also, when the distance between each point of one point group and the nearest point of another point group to the point was shorter than 600 mm, the nearest point was considered a corresponding point.

4.3 Experimental result

In the example, the robot is placed at place "1" at first and the destination place is place "4". As a result of the Dijkstra method, the robot moved from place "1" through place "2" and place "5" to place "4". At place "2", place "5" and place "4", image matching and ICP matching was performed when the robot state is Outside B. Fig.9 shows images captured by the robot during the navigation, matched database images in the places of the hybrid map and voting rate in the case of the highest voting rate in image matching at place "2" and place "5". The result of ICP matching at place "2" and place "5" is shown in Fig.10. In this figure, red points represent grids whose occupation probabilities are over 50 percent in the occupancy grid map of each place, blue points represent scan data of LRF at robot position estimated roughly by image matching, and green points represent scan data of LRF at accurate robot position corrected by ICP matching. The result of state transition in navigation is shown in Fig.11. Fig.9 shows these two images are comparatively similar. That means place recognition based on image matching was successful. Fig.10 shows ICP matching in the initial rough place was also successful since the suitable position is searched by image matching. As a result, localization of the robot was achieved and navigation to the destination place was successful, carrying out a state transition as shown in Fig.11.

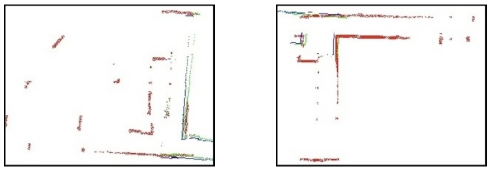
Captured images   Matched images   Voting rate



Place2   26.1%

Place5   34.4%

Fig.9 Matching image of navigation



Place2   Place5

Fig.10 ICP matching of navigation

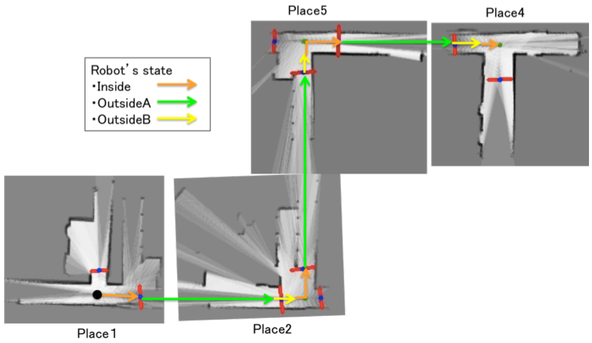


Fig.11 State transition of navigation

5 CONCLUSIONS

The navigation system using the hybrid map was developed. And, autonomous navigation using the hybrid map was achieved. Experimental results showed validity of the hybrid map and the navigation system. The experiment of the map generation and navigation in more complicated environment is conducted from now on, and detailed evaluation of the approach should be performed.

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