Obstacle Avoidance and Path Planning Using Color Information for a Biped Robot Equipped with a Stereo Camera System

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Abstract— **It is necessary for a biped robot to recognize a surrounding environment when moving to the destination. This paper presents a method for path planning and obstacle avoidance for the biped robot. In our approach, the robot obtains color information and distance information of objects from images captured by a stereo camera system. Then, the robot generates a 2D grid map which locates floor regions, bump regions, obstacle regions and unmeasured regions. The robot decides its path by using the 2D grid map. Experimental results show the effectiveness of the proposed method.**

***Keywords*— Biped robot, Stereo camera, Obstacle avoidance, Path planning, Color information**

I. INTRODUCTION

Recently, autonomous robots are expected to work in environments where interaction with humans is very common. Examples are housework and nursing robots at home, monitoring and guard robots in facilities. To realize robots to act in such environments, the study of biped robots has been made because they can move flexibly by using many degrees of freedom when there is a restriction in the width and the height of spaces for robot movement.

Visual function is necessary to recognize a surrounding environment for the robot to move to the destination. Umeda et al. [1][2] proposed a method in which the robot autonomously moves while avoiding obstacle regions by detecting flat floor regions and obstacle regions using a small range image sensor.

Sabe et al. [3] proposed a method in which the robot autonomously moves while generating its path considering obstacles in flat floor regions by using a 2D grid map obtained with a stereo camera system. Gutmann et al. [4][5] proposed a method in which the robot autonomously moves while generating its path considering bump regions in a 2.5D gird map. Kanehiro et al. [6][7] proposed a method in which the robot passes through a gate while generating its path considering a 3D gird map obtained with a stereo camera system.

The above methods work only in limited environments, because the robot should recognize various obstacles such as bumps, stairs, doors and desks existing in the environment and then select movements according to the recognition result.

The purpose of our study is to construct a frame by which the robot recognizes the environment and moves to the destination.

Specifically, we propose a method in which the biped robot generates an environment model using a stereo camera system, plans its path to the destination, and selects an appropriate movement.

II. PRECONDITION

The preconditions for the proposed method are as follows.

- Objects existing in the environment are classified into the following three classes.
  - Floor regions
  - Bump regions
  - Obstacle regions
- In the environment there exists a landmark whose position and size are known.

In addition to the first condition, the robot recognizes objects in the environment by color information. Although, the environment where the robot moves is a 3D environment, a generated map is in the form of 2D grids, which can represent positions of objects in each class.

With the second condition, the robot estimates its position and orientation in the environment.

III. PROPOSED METHOD

Figure 1 presents the flow of the proposed method.

In the first step, the robot obtains color information and distance information of objects from images captured by a stereo camera system. In addition, the robot estimates its position by using a landmark installed all over the environment.

In the second step, the robot generates a 2D grid map which locates floor regions, bump regions, obstacle regions and unmeasured regions. In this step, each grid on the 2D grid map is determined whether it is a floor region, a bump region, an obstacle region, or an unmeasured region by using color information.

In the third step, the robot decides its path by using the 2D grid map. At first, the robot generates the 2D grid map considering interference regions of the biped robot with the obstacle regions. Here, a problem to generate the path to the destination is transformed into that of finding the shortest path along nodes of the 2D grid map. The A* search [8] is used for path planning.

In the forth step, the robot selects its movement sequence based on its path plan.

The above process flow is being repeated until the robot reaches to the destination.

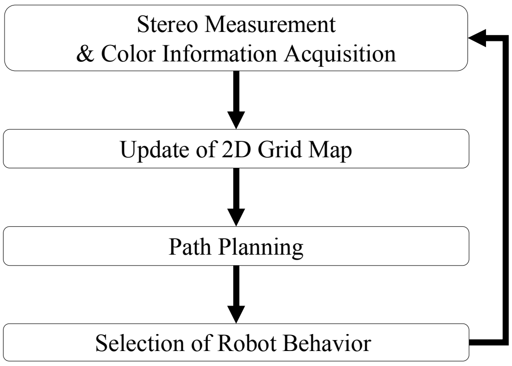


Fig. 1 Proposed method.

IV. Stereo Measurement

In this study, we use a stereo camera system installed on the biped robot to capture stereo images, which convey color information and distance information of objects in a circumference environment. Figure 2 shows the overview of environment measurement by the robot. Figure 3 shows stereo image examples acquired in Fig. 2.

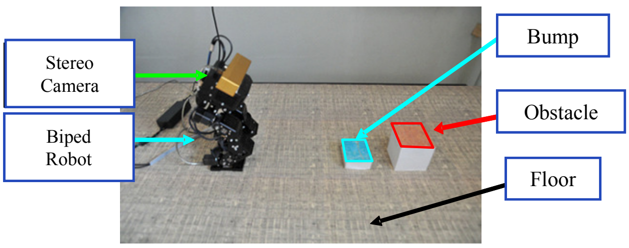


Fig. 2 Biped robot equipped with a stereo camera system.

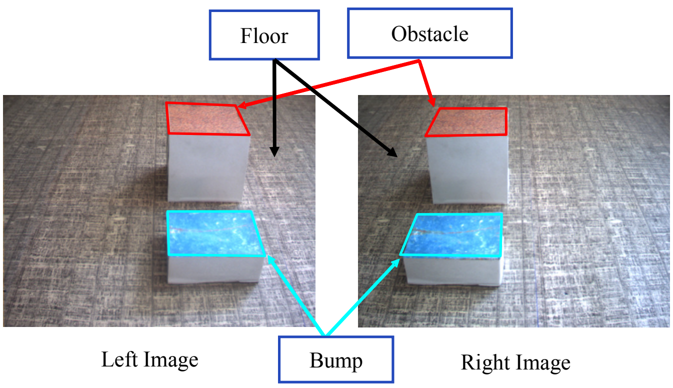


Fig. 3 Stereo image.

Our method judges whether the measurement point belongs to floor regions, bump regions or obstacle regions by using color information, and determines the positions of these regions by using distance information. We also define regions where the robot cannot measure as unmeasured regions. These regions happen to exist because there is the problem of occlusion and the limited field of view of the stereo camera system.

In addition, an error in positioning of the robot in the environment occurs if we estimate its position only by odometry. It is necessary for the robot to know its position in the map precisely so that it becomes capable to integrate the on-site measurement data with the already given 2D grid map. Therefore in our method, we estimate the position of the robot by using stereo observation with a landmark [9].

V. Map Generation

This section explains a method for generating a 2D grid map by color information and distance information of measurement points.

First, a 3D map made with the measurement points acquired from a stereo camera is generated. Figure 4 shows the 3D map acquired from a stereo image of Fig. 3.

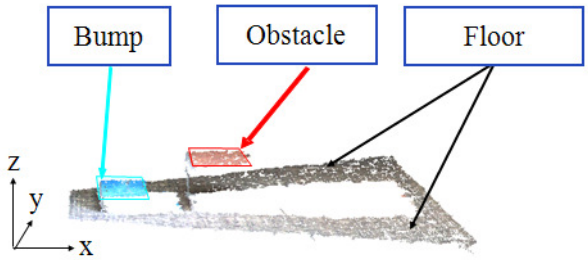


Fig. 4 3D map.

Next, each grid on the 2D grid map is classified into floor regions, bump regions, obstacle regions, or unmeasured regions by projecting the 3D map to the 2D grid map. Figure 5 shows the 2D grid map generated with the measurement points of Fig. 4. Gray grids of Fig. 5 show the floor regions, blue grids show the bump regions, red grids show obstacle regions and white grids show unmeasured regions.

At this time plural measurement points might be projected to one grid in the 2D grid map. When color information on the same measurement point is different, the major color in the measurement point is selected and the grid is judged whether it is floor regions, bump regions, or obstacle regions. When the measurement point is not projected to the grid, the grid is judged to belong to an unmeasured region.

In the proposed method, the measurement procedure is repeated, and then the 2D grid map is updated continuously (Fig. 6). As the robot moves, unmeasured regions might be reduced, and the robot realizes appropriate movements to the destination.

VI. Path Planning

The 2D grid map is used for planning so that the biped robot can safely and efficiently move to the destination.

A. Configuration Space

The configuration space is the space expressing the robot as a point without size [10].

In this study, the biped robot is approximated to the cylinder whose axis coincides with the center of robot's turn as shown in Fig. 7. Thus the robot is treated in two dimensions without posture and the size of the robot is considered to be a cylinder size.

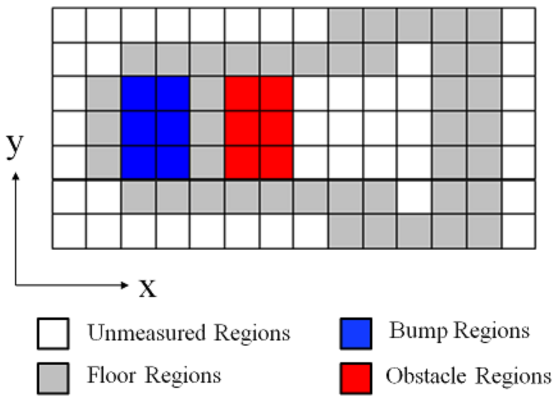


Fig. 5 2D grid map.

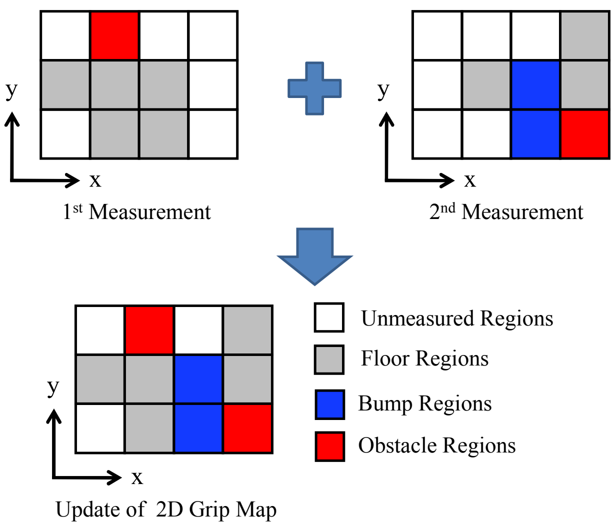


Fig. 6 Update of 2D grid map.

B. A Search*

At first, a cost is given to each set of adjacent grids in the 2D grid map of the ambient environment for the robot [11].

The movement from a floor grid to another floor grid can be easily done by the robot. Let the cost in this case be C1.

The movement from a floor grid to a bump grid, and vice versa also can be done by the robot. Let the cost in this case be C2. Here, C2 is higher than C1 because the movement between the different height takes more time than that between the same height.

The movement from a floor grid to an unmeasured grid takes more time than the above two cases owing to additional measurement. Then, the cost in this case, C3, is higher than C2.

Paths crossing obstacles are forbidden because the robot cannot move over obstacles.

Next, we define each grid of the 2D grid map as a node connecting to neighboring grids and define the path planning problem as a search problem on this graph (Fig. 8).

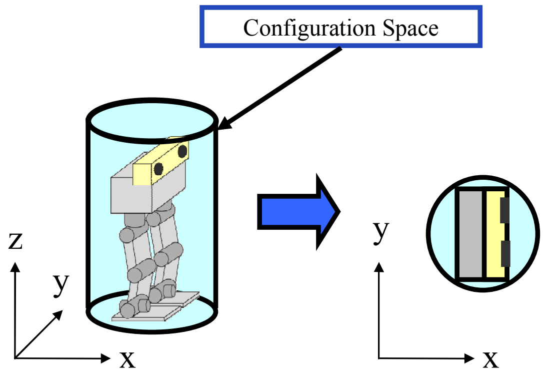


Fig. 7 Configuration space.

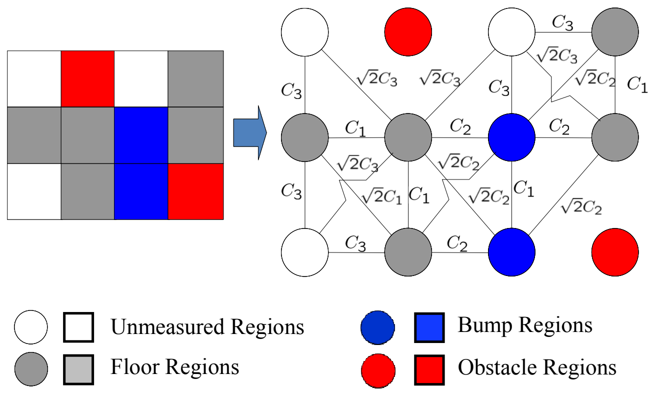


Fig. 8 Graph search.

Graph search is realized by the A* search algorithm. Our evaluation function for the A* search is:

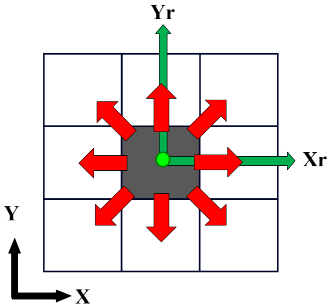
$$f^*(n) = g(n) + h^*(n) \qquad (1)$$

Where $f^*(n)$ is the optimally estimated cost for passing through the node n. $g(n)$ is the path cost from the starting node to the node n. $h^*(n)$ is the estimated path cost from the node n to the goal node.

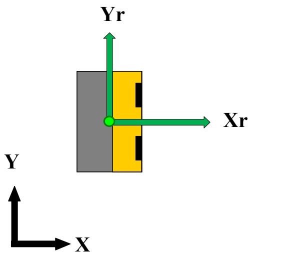
VII. Selection of Robot Behaviour

We perform the movement selection of the biped robot according to the result of path planning.

When the generated path lies on floor regions, the robot moves from the grid of the present position to the next grid, in one of the eight directions shown in Fig. 9(a). At first, the robot selects the behavior of turning to the direction of the grid to move (the robot rotates its robot coordinate system so as to make its Xr coordinate axis in the same direction to move) . Next, by selecting advancing movement the robot moves to the next grid.



(a) Direction of Motion.



(b) Robot Coordinate System.

Fig. 9 Selection of robot behaviour.

When the grid of the present position of the robot is in the floor region and the next grid is in the bump region, the robot selects the movement of stepping up on the bump, as show in Fig. 10. Similarly, when the grid of the present position of the robot is in the bump region and the next grid is in the floor region, the robot selects the movement of stepping down to the floor, as show in Fig. 11.

VIII. EXPERIMENT

A. System Configuration

The composition of an experiment system is as follows. A stereo camera system is installed to a biped robot and transmits images to a computer by cable. The computer processes the images and executes path planning and behaviour selection. The behaviour commands for the biped robot are transmitted from the computer by cable, and the robot moves according to the commands.

We used Bumblebee2 as the stereo camera. The size of acquired images is 512 × 384 pixels. The base line length of the camera was approximately 12cm.

The computer had 3GB memory and Intel Core2 Quad 2.4GHz CPU.

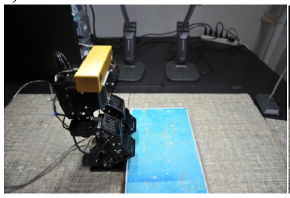
The biped robot we used is e-nuvo WALK ver.3. The size of the robot is approximately 35cm × 16cm × 14cm. The number of degrees of freedom of the robot joints is 6 for one leg, 2 for ankles, 3 for groins, and 1 for knee.

B. Experimental Field

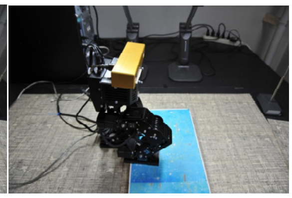
Stereo measurement is difficult when objects have surfaces of poor texture. Therefore, objects with rich texture were used in the experiment. Figures 12(a), (b) and (c) show the textures of the floor regions, the bump regions and obstacle regions, respectively. The landmark for self-localization was in the form of circle with the radius of 7.5cm (Fig. 12 (d)).

The size of the experimental field was 180cm × 100cm (Fig. 13). The point shown with a black cross in the experimental field is the destination for the robot. A broken circle with 10cm radius was drawn around the destination.

The pitch of each grid of a 2D grid map was 5cm × 5cm.The costs between grids in the A* search were set as C1=1, C2=5 and C3=20.



(a)



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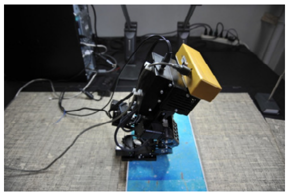
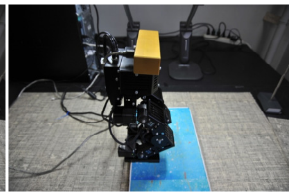
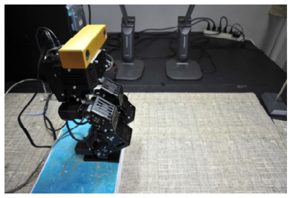


(c)

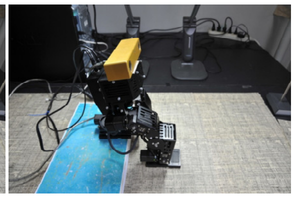


(d)

Fig. 10 Step up.



(a)



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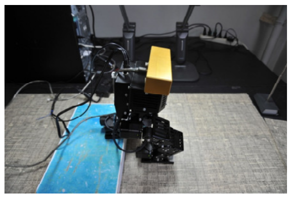
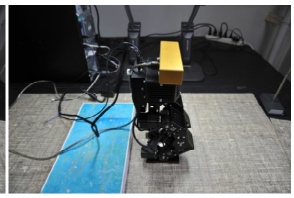
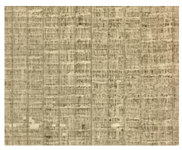


(c)



(d)

Fig. 11 Step down.



(a) Floor.

(b) Bump.

(c) Obstacle.

(d) Landmark.

Fig. 12 Experimental field (1).

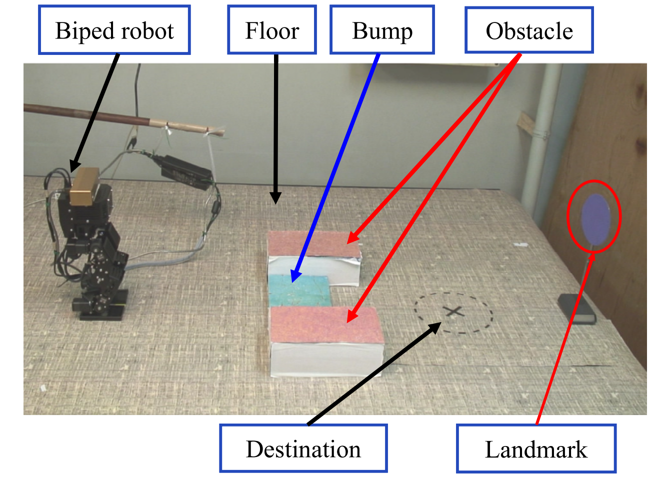


Fig. 13 Experimental field (2).

C. *Experimental Result*

We conducted experiments of robot movement in the following three environments.

- Environment having only floor regions and obstacle regions
- Environment having only floor regions and bump regions
- Environment having floor regions, bump regions and obstacle regions

In the first experiment it was confirmed that the robot moved to the destination while avoiding obstacle regions, and in the second experiment that the robot moved to the destination while stepping up and down between the floor regions and the bump regions. Figure 14 and 15 show the experimental results of the first and second experiments, and show the 2D grid maps (left figures) and the appearances of the robot measuring the ambient environment (right figures). In the 2D grid map, gray grids, blue grids, red grids and white grids represent floor regions, bump regions, obstacle regions, and unmeasured regions, respectively. The arrow in their result shows planned path along which the robot was scheduled to move to the destination. Figures 14 (a), (b) and (c) show the measurement results of the first time, the third time and the sixteenth time, respectively. By the measurement result of the first time, the robot could not recognize obstacle regions and planned its path to go straight to the destination. But, by the measurement result of the third time, the robot recognized the obstacle and planned its path again to avoid obstacle regions. Figures 15 (a), (b) and (c) show the measurement results of the first time, the sixth time, and the ninth time, respectively. Here, the robot judged that it would be faster to go over the bump to the destination than to detour around it.

The third experiment was done for comparison of our approach with a reference method providing a result of path planning where the robot can move only in floor regions. Figures 16 and 17 show the experimental results of the third experiment. Figure 16 shows the path given by the referred method. In contrast, Figure 17 shows the path given by our approach. Comparing the two results, the movement distance by our approach is approximately 100cm shorter, and the movement time by our approach is approximately 5 minutes shorter. Consequently, our approach is superior in the movement distance and the movement time to the method which regards bump regions as obstacles.

IX. Conclusion

In this paper, we propose a method for biped robots to move to the destination. The robot obtains color information and distance information from images captured by a stereo camera system. Then, the robot generates a 2D grid map that locates floor regions, bump regions, obstacle regions and unmeasured regions. The robot decides its path by using the 2D grid map, and selects the appropriate movement. Experimental results showed the effectiveness of the proposed method.

As future works, we should make the following improvements. For environment recognition, we should recognize wall regions, door regions and slope regions existing in an environment. For map generation, we should generate a 3D grid map to recognize a 3D environment. For motion planning, the robot should climb stairs and go up on slope regions.

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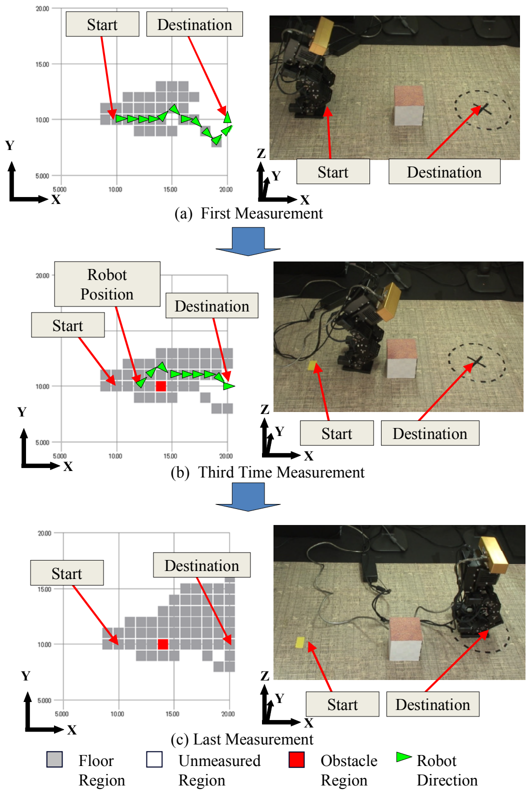

Fig. 14 Environment having only the floor regions and obstacle regions.

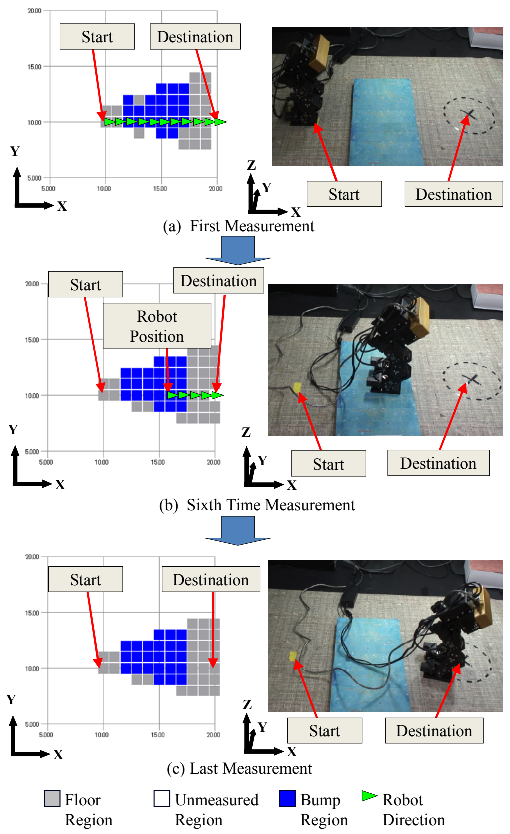

Fig. 15 Environment having only the floor regions and the bump regions.

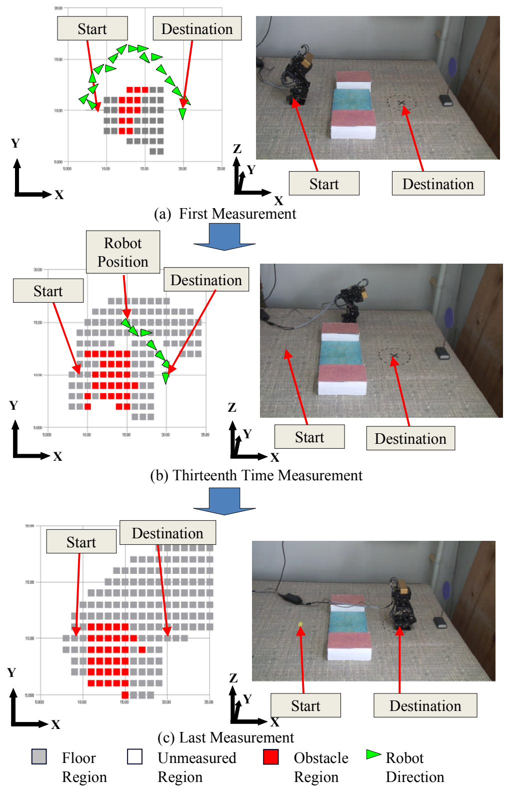

Fig. 16 Environment having the floor regions, the bump regions and obstacle regions (the path given by the referred method).

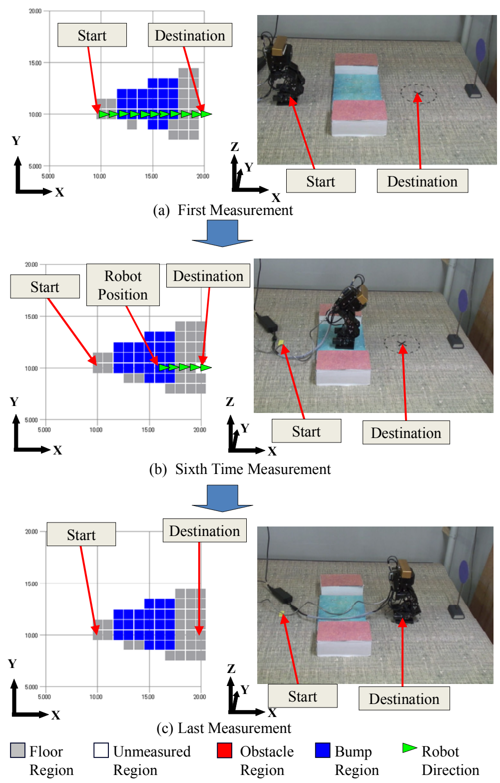

Fig. 17 Environment having the floor regions, the bump regions and obstacle regions (the path given by our approach).