A BASIC STUDY ON PATH TEACHING METHOD FOR A MOBILE ROBOT USING A DIGITAL CAMERA

Hidenari MAKINO*, Shigehiro YAMAMOTO**, Teruo AZUKIZAWA** and
Takeshi HASHIMOTO***

*Graduate School of Science and Technology
Kobe University, Japan
e-mail: 017d983n@y04.kobe-u.ac.jp
**Faculty of Maritime Sciences
Kobe University, Japan
e-mail: { yamamoto, azuki }@maritime.kobe-u.ac.jp
***Faculty of Engineering
Shizuoka University, Japan
e-mail: tethash@ipc.shizuoka.ac.jp

Abstract

This paper proposes a novel path teaching method for a mobile robot. In this method an operator takes pictures at significant points such as turning points, half way points and a destination on robot's path by a digital camera. Then, the operator teaches the robot landmarks to recognize the images and actions for the robot to take at the significant points. The robot travels autonomously searching the landmarks and obeys the instructions when it recognizes reaching the significant points. By using this method, it is possible to teach paths for the mobile robot more easily. In this paper, outline of the proposed method and results of fundamental experiments in both indoor and outdoor environment to confirm possibility of the method are described.

Keywords: mobile robot, path, teaching, digital camera, image processing.

1. Introduction

In order for a mobile robot to travel autonomously, recognition of its path is very important. Although various methods have been proposed about navigation of mobile robots [4], many techniques use a "map", or a model of the environment. Many researchers have been studying localization of a robot based on a map. GROMANN et al. described a robust position-tracking method with sonar sensors [6]. A laser scanner and a vision system are also used for robot localization [1, 8, 10].

It is not an easy task for an operator of a robot to make such a map. Therefore, in order to build a map automatically, researches on simultaneous localization and map building (SLAM), that is, a robot explores in unknown environment and builds a map of the environment by itself, are conducted as shown in [3, 5, 7]. However, these methods can be adapted only in the restricted environment with some special conditions, and they are not much efficient in case of travelling long distances or on the regular path for routine tasks.

There is another approach to make the map more easily. MATSUMOTO et al. reported the study that made a robot travel based on a series of images that were recorded while an operator manually controlled the robot on the desired path [12]. Similar research that a robot builds a map using stereo vision while it is navigated by remote control of an operator is described in [9]. The method described in [11] employs panoramic views obtained during human guidance in outdoor environment. A point in common among these studies is to make a robot build a map during manual navigation of the robot. Although the operator does not have to make the map directly in these methods, it is not so easy to control the robot manually. Moreover, it is difficult for the robot to move off the instructed path flexibly since the path is continuously specified.

In this paper, a novel method to teach a mobile robot its path easily is described. The method uses a digital camera for path teaching. That is, an operator takes images at the significant points, such as a start point, turning points, and a destination point, with the digital camera. Then, he/she teaches both robot's actions and landmarks based on these images. The robot can recognize the current locations by comparing the images obtained during autonomous travel, with the pre-recorded images.

The proposed method has an advantage compared to the remote control methods mentioned above since the operator does not have to take the real robot along the path but only a camera. Matching between the pre-recorded images by the digital camera and images obtained during autonomous navigation is a key technique to realize the proposed method. A similar study on matching of visual landmarks for robotic homing has been reported in [2]. The objective of that study is visual navigation of a mobile robot to a goal point based on the image obtained at the goal point. However, the literature describes only short distance navigation to the goal point from the locations where the robot can look at the goal point using a single image at the goal point. On the other hand, the authors aim at making the robot travel along a long path that includes corners, intersections and so on using several images at such significant points.

This paper describes the outline of the proposed method and results of fundamental experiments in both indoor and outdoor environment in the following sections.

2. Path Teaching Using a Digital Camera

2.1. Overview

When you direct someone to some place, you can say like "Go straight on this way and turn left at the signboard that says 'ABC'." The objective of the proposed method is to realize the similar way that teaches a mobile robot its path. Because it is difficult for a robot to recognize a scene in unknown environment, the authors propose taking a picture of the scene with a digital camera in advance. *Fig. 1* illustrates a general idea of the path teaching method proposed in this paper. An
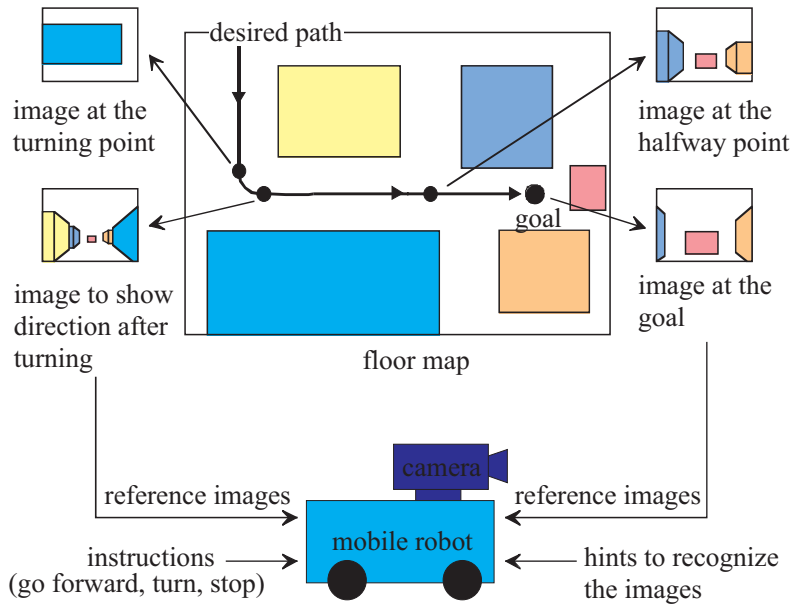
Fig. 1. Illustration of the path teaching method.

outline of the procedures is as follows:

1. First, an operator takes images with a digital camera at significant points such as a start, turning points, halfway points and a goal. We call them "reference images."
2. Next, the operator teaches the mobile robot its action such as "go forward, turn and stop" with the reference images. The operator also gives the robot hints such as landmarks to recognize the images.
3. Finally, the robot travels autonomously between the significant points and takes an action when it recognizes arrival at one of the points by comparison between images at the current positions and the reference image corresponding to the point.

The following points are mentioned as an advantage of this technique:

1. All the operator has to do is to take some images and give the robot some simple instructions.
2. In order to change a part of the path, the operator has only to retake images at new points on the path. The robot can be adapted to environmental change similarly.
3. Since the instructed path to the robot is not a continuous path but discrete points, the robot can take flexible action between the points. For example, if there is an obstacle on the path, the robot will avoid it by some method.

As mentioned above, the key idea of the proposed method is to give the robot the necessary and minimum hints to recognize its path. Especially, the load and failure of image processing are reduced by the operator's help, for example, choosing distinctive objects as landmarks in order for the robot to easily recognize the images. This is the same way as you choose easy objects to find as landmarks when you tell a person the way. The aim of this study is to navigate the robot to a final destination, and it is not intended to control the robot based on strict localization.

2.2. Control of the Robot

In order to realize the proposed method, the robot has to do two tasks while it is travelling autonomously. One of them is to decide direction to move. Another task is to recognize arrival at one of the significant points and to take the instructed action. In the proposed method, the reference images are employed to help execution of these tasks. Following paragraphs explain the method.

For example, we consider the path that includes turning left as shown in *Fig. 2*. First, an operator takes a reference image at the turning point. Then, the operator inputs the image into the robot and indicates a square region that includes a signboard "ABC" as a landmark in the reference image. Needless to say, objects that have a distinctive feature in the scene and do not change soon must be selected as landmarks. The operator also instructs robot's action "turn left" at the same time. The kind of actions includes "go straight", "turn left", "turn right" and "stop" in case of a prototype robot described in this paper.

After the teaching stage mentioned in above paragraph, the robot starts autonomous navigation. The robot scans each "current image", which is obtained during autonomous travelling, and detects the region that has the highest correlation with the indicated region in the reference image. This is the same as template matching. It is executed changing the size of the template, that is, the region of the landmark in the reference image since the size of the landmark in the current image varies due to distance between the robot and the object. *Fig. 3* illustrates this procedure. Let $r_r(x, y)$, $g_r(x, y)$ and $b_r(x, y)$ be red, green and blue values at the coordinates (x, y) on the reference image. And $r_c(x, y)$, $g_c(x, y)$ and $b_c(x, y)$ are those on the current image. Then, the robot finds Δx, Δy and α that maximize the correlation,

$$r(\Delta x, \Delta y, \alpha) = \frac{\sum_{x,y \in A} (R_{rc} + G_{rc} + B_{rc})}{\sqrt{\sum_{x,y \in A} (R_{rr} + G_{rr} + B_{rr}) \sum_{x,y \in A} (R_{cc} + G_{cc} + B_{cc})}} \tag{1}$$
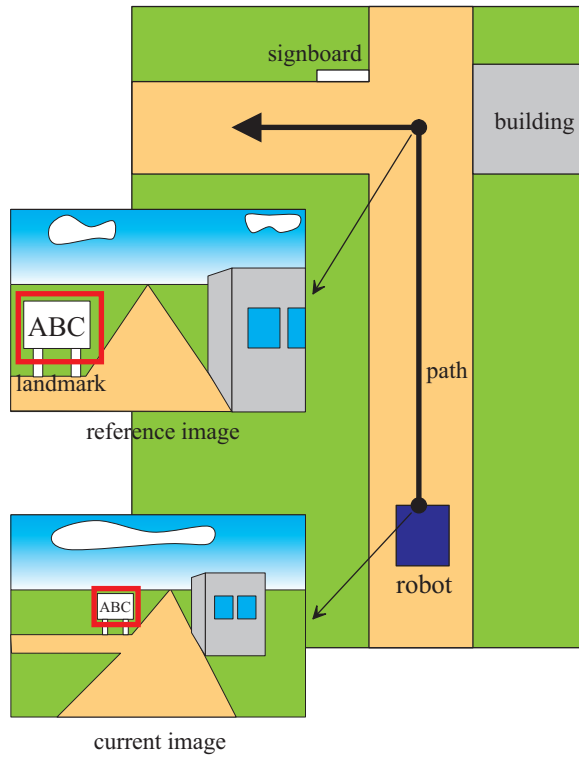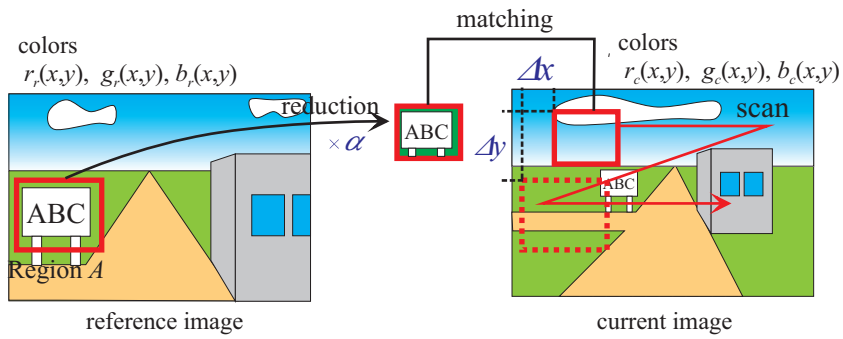
Fig. 2. Control method of the mobile robot.

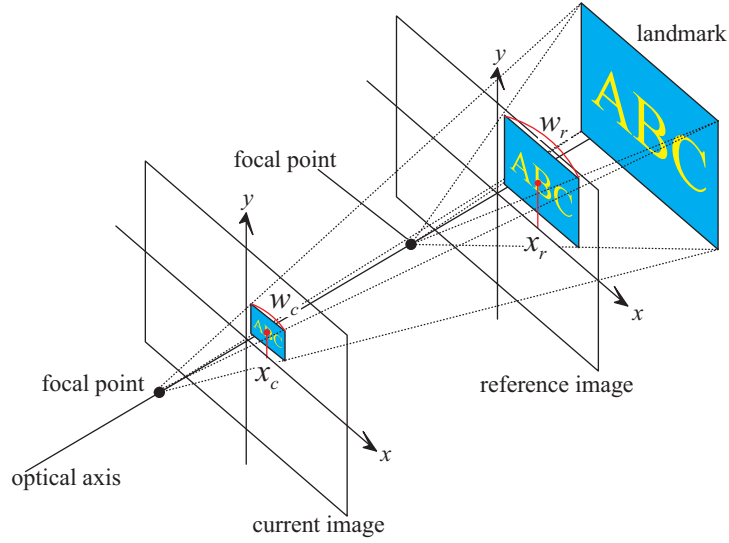*Fig. 3*. Detection of the indicated landmark.

Fig. 4. Definition of the coordinate system and pinhole camera model.

where A is the indicated region on the reference image, and

$$
\begin{aligned}
R_{rc} &= r_r(x, y)r_c(\alpha x + \Delta x, \alpha y + \Delta y), \\
G_{rc} &= g_r(x, y)g_c(\alpha x + \Delta x, \alpha y + \Delta y), \\
B_{rc} &= b_r(x, y)b_c(\alpha x + \Delta x, \alpha y + \Delta y), \\
R_{rr} &= r_r^2(x, y), \\
G_{rr} &= g_r^2(x, y), \\
B_{rr} &= b_r^2(x, y), \\
R_{cc} &= r_c^2(\alpha x + \Delta x, \alpha y + \Delta y), \\
G_{cc} &= g_c^2(\alpha x + \Delta x, \alpha y + \Delta y), \\
B_{cc} &= b_c^2(\alpha x + \Delta x, \alpha y + \Delta y).
\end{aligned}
\tag{2}
$$

The robot is controlled according to the detected result of the landmark. Let x_r and x_c be abscissas of the center point of the indicated region in the reference image and the detected region in the current image, respectively, as indicated in *Fig. 4*. We assume that the camera is represented by a pinhole camera model and optical axes of the reference image and the current image are the same for simplicity. Then, the ratio x_c to x_r becomes equal to α , which indicates a ratio of the two regions' sizes. The heading of the robot is controlled such that the value of x_c becomes close to αx_r. Although this way may seem rather rough, the method works well because the

objective of this study is not to control the robot strictly on the path but to navigate it to the destination.

The ratio α is also used to judge robot's arrival at the significant point. That is, when the α becomes about 1.0, the robot will start turning left in case of this example.

The operator may specify two or more landmarks in the reference image. In that case, the landmark that has the highest correlation between the reference and current image is chosen in order to control the robot. This enables the robot to adapt a small change of the environment, for example, in case that one of the landmarks is occluded. However, more consideration will be required about the most effective way to make good use of several landmarks as a future work for robust navigation.

3. Experimental Results

3.1. Mobile Robot

Fig. 5. Prototype mobile robot.

Fig. 5 shows a picture of the mobile robot. It is 350 mm long, 300mm wide and 250 mm high without the camera and PC. It has two powered wheels for driving and two caster wheels for balance. The two powered wheels can be independently driven at different speeds or can be driven in opposite directions to make the robot turn in place. The driving motors has rotary encoders and they are used for controlling speeds of the motors and obtaining odometry data although the odometry data are not used in this study. The robot runs at a speed of 100 mm/s

in the experiments. A V25-10MHz CPU board on the robot manages the low level control such as driving the motors.

A note type PC, of which CPU is Pentium III − 650MHz, on-board the robot processes images and makes high level decisions to control the robot. The PC communicates with the V25 CPU board via RS-232C. Both reference and current images are obtained by a digital video camera with a wide-angle lens. The field of view is about 80 degrees. The images are obtained with PCMCIA colour frame grabber card. Original resolution of the images is 640 × 480 pixels, and 24 bits colour, 8 bits for each *R*, *G* and *B*. However, the size of the images is reduced to 320 × 240 pixels (24 bits colour) because of processing speed.

The operating system is Windows Me and software for controlling the robot is written in Boland C++ Builder Ver.5. The processing speed is a few frames per second.

3.2. Indoor Experiment

The experiment was conducted in a laboratory shown in *Fig. 6.* There are some desks and laboratory equipment in the laboratory. The instructed path consists of "go straight, turn left, go straight and stop". The total length of the path is about 10m. First, an operator took pictures as reference images by the digital camera at 6 points, that is, start point, turning point, goal point and halfway point at intervals of 2 m. *Fig. 7* shows examples of the reference images and landmarks. The reference image in *Fig. 7(a)* is that of the start point and used to decide the initial direction of the robot at the start point. In this case, the operator directed a group of fluorescent lights on the ceiling and an electric fan with other equipment as landmarks. Two reference images were taken at the turning point. One of them is to teach the robot the location where it should turn (see *Fig. 7(b)*). Another reference image, shown in *Fig. 7(c)*, at the turning point is used to indicate the direction to move after turning left. The last reference image at the goal point is indicated in *Fig. 7(d).* A fire extinguisher was specified as a landmark.

Fig. 8 shows an example of the paths on which the robot moved. Although the robot turned left 150mm before the instructed point in this case, it was not a matter since the robot could get to the destination. The experiment of navigating the robot was conducted 5 times on the same conditions. The robot could reach the destination all the time, and errors of the path were less than 200 mm.

Fig. 9 shows another path in indoor environment. The robot starts at a point in an office room, goes out from the room, and turns left. Then, it moves about 4m along the corridor, turns left, and goes in the room again through another door. *Fig. 10* indicates some of the reference images and landmarks of this path. The robot also reached the goal point as shown in *Fig. 11*.
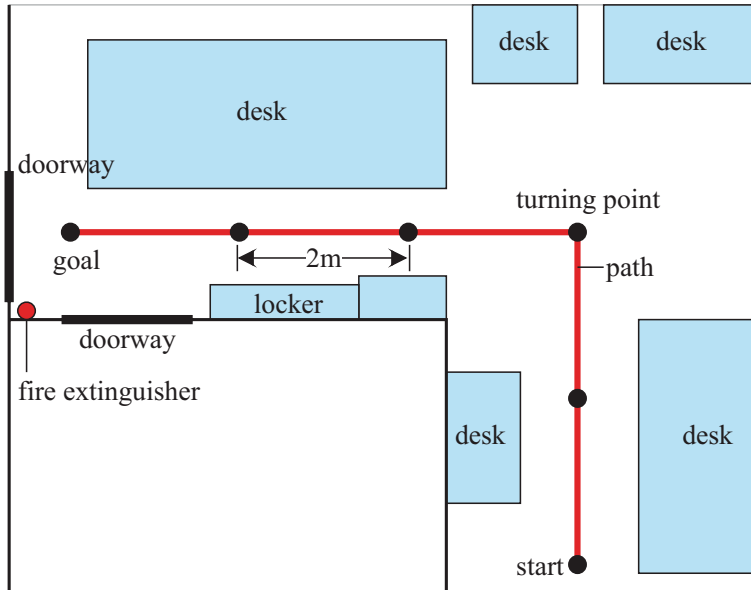
Fig. 6. Experimental conditions in the laboratory.

3.3. Outdoor Experiment

Fig. 12 shows the environment of an outdoor experiment. The experiment was conducted in our campus. There are buildings and some trees on the side of the street. The assumed path is "go straight, turn right, go straight and stop", and the total length of the path is about 18m. The reference images were taken at the start point, the turning point, and the goal point and half way points at intervals of 3m between them. *Fig. 13(a)* indicates the reference image at the start point, which is used to obtain the initial direction to move. The landmark is just a part of the scene ahead of the robot. The reference image indicating the turning point is shown in *Fig. 13(b)*. A traffic sign was specified as a landmark to recognize the point. *Fig. 13(c)* is also the reference image at the turning point and it indicates the robot's heading after turning right. Finally, the reference image, where another traffic sign is directed as a landmark, is illustrated in *Fig. 13(d)*.

Fig. 14 indicates an example of the experimental results. The errors of the path were larger than those of the indoor experiment. However, as a result of 3 trials of robot's navigation, it was confirmed that the robot could reach the destination.
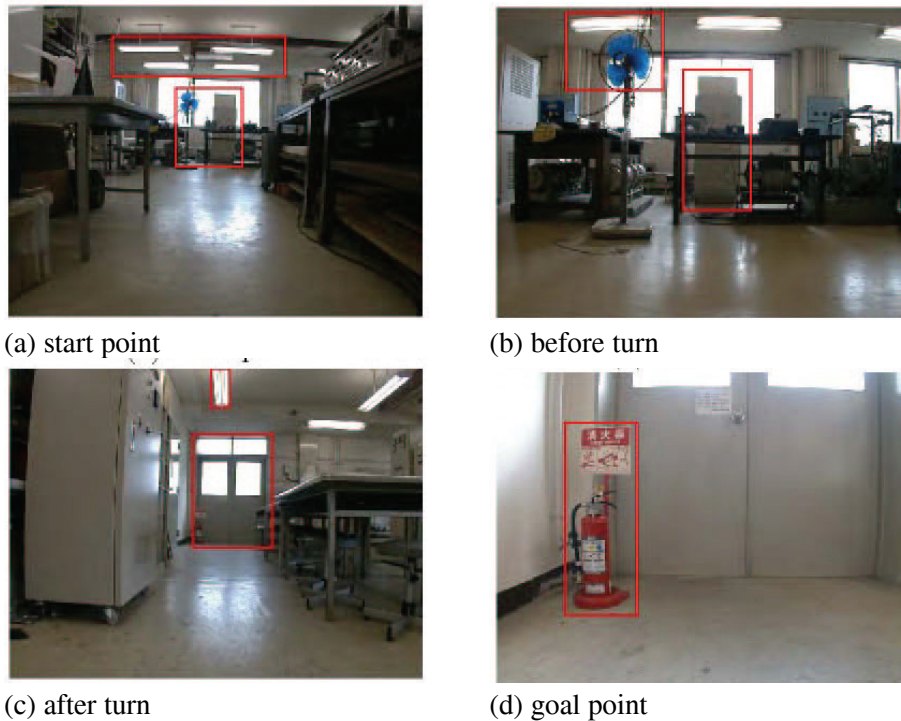
(a) start point

(b) before turn

(c) after turn

(d) goal point

Fig. 7. Reference images and landmarks for the path in the laboratory.

4. Conclusions

In this paper, a novel method for path teaching to a mobile robot was proposed. The method uses reference images obtained by a digital camera at significant points such as a start point, turning points, halfway points and a goal point. A merit of the proposed method is its simple and easy way to teach the robot a route to a destination. The objective of the method is not to control robot's locations on a path accurately but to navigate the robot to the destination anyway. Both the indoor and outdoor experiments confirmed a possibility to put the method to practical use.

The matching between reference images and images obtained while the robot is moving is a key technique of the proposed method. In this paper, we simply chose the technique of template matching using landmarks that were indicated by an operator. The method worked well because the operator could choose distinctive objects that were easy to be detected by image processing as landmarks. However, a more robust image matching technique, which is not affected by environmental change, must be developed as a future work. High resolutionality that a digital camera has might be useful for robust matching, although the experiments presented in this paper were conducted with relatively low resolution because of processing speed. In
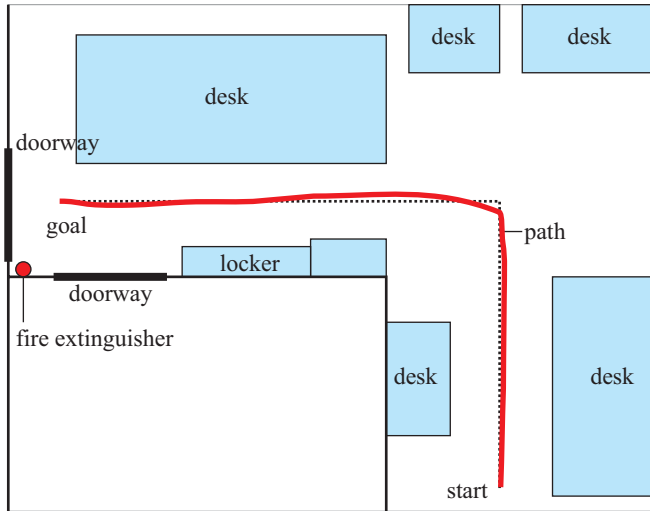
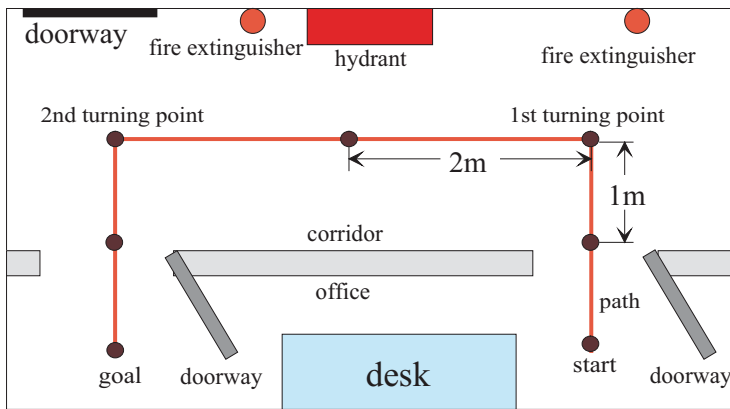*Fig. 8.* A result of the experiment in the laboratory.

Fig. 9. Experimental conditions in the corridor.

addition, control method of the robot between significant points must be considered. The authors are now working on a method that the robot automatically detects the area where it can move by means of using colour and edge information in images. This, combined with landmark-based method described in this paper, enables the robot to travel toward the next significant point autonomously avoiding obstacles.
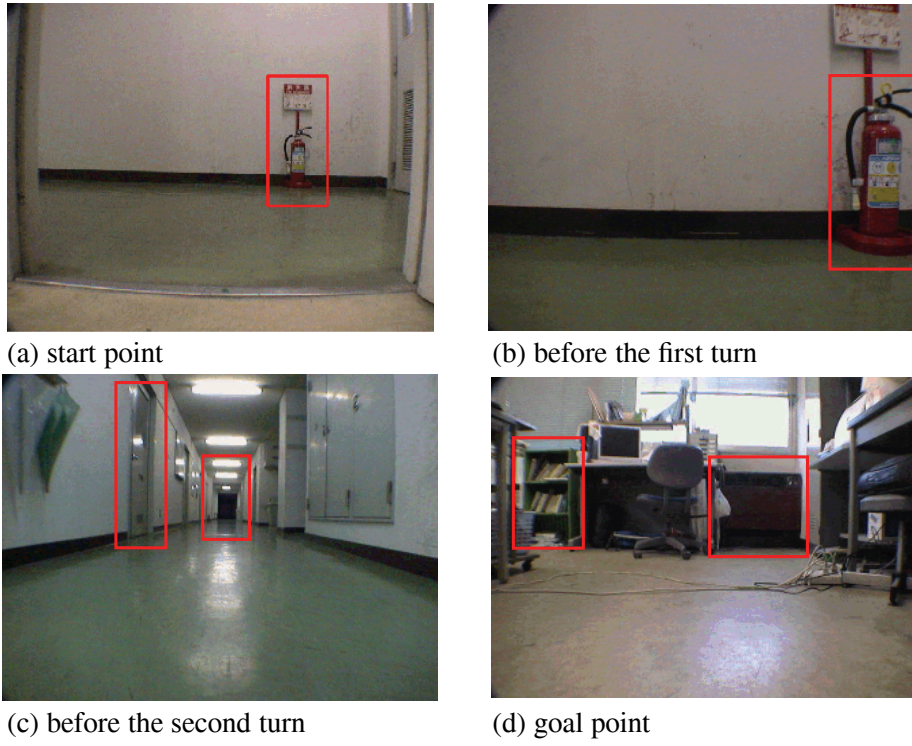
(a) start point

(b) before the first turn

(c) before the second turn

(d) goal point

Fig. 10. Reference images and landmarks for the path in the corridor.
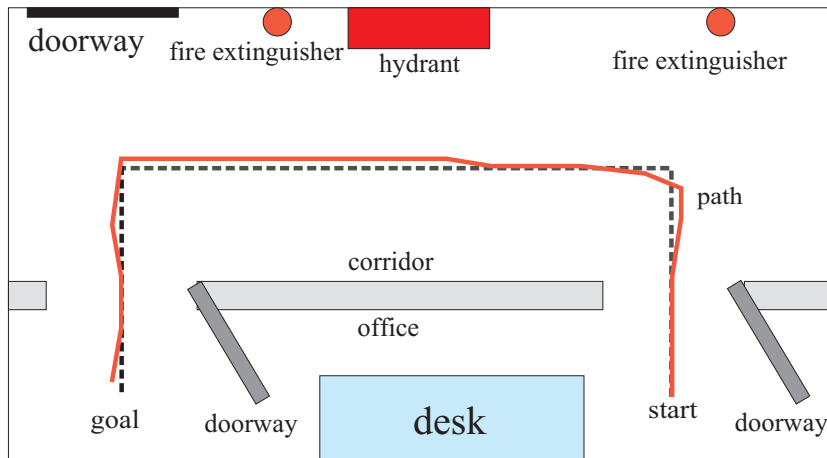

Fig. 11. A result of the experiment in the corridor.
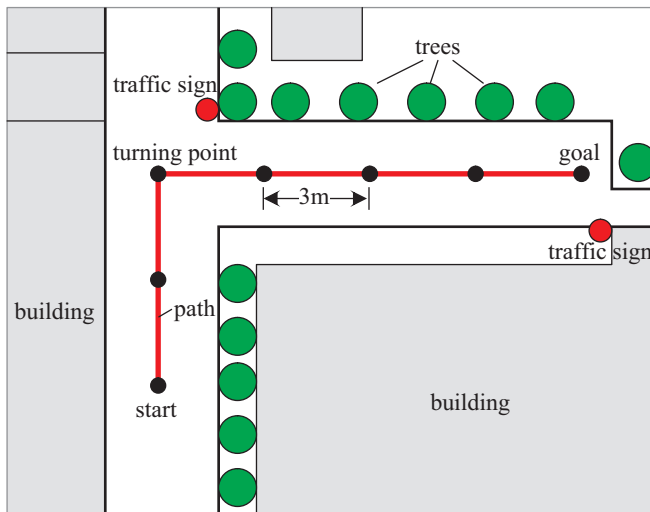
Fig. 12. Experimental conditions in outdoor environment.

(a) start point

(b) before turn

(c) after turn

(d) goal point

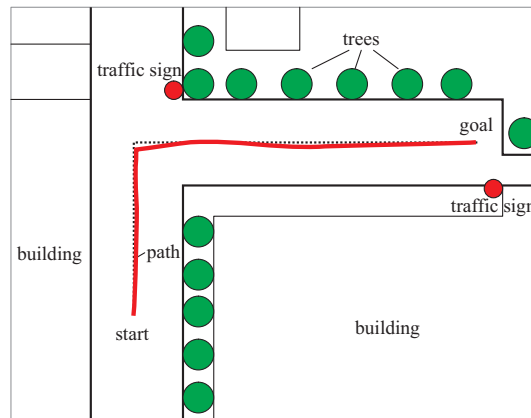Fig. 13. Reference images and landmarks in outdoor experiment.

Fig. 14. A result of outdoor experiment.

References

[1] ADORNI, G. – CAGNONI, S. – ENDERLE, S. – KRAETZSCHMAR, G. K. – MORDONINI, M. – PLAGGE, M. – RITTER, M. – SABLATNöG, S. – ZELL, A., Vision-based Localization for Mobile Robots, *Robotics and Autonomous Systems*, **36**, (2001), pp. 103–119.

[2] CASSINIS, R. – DUINA, D. – INELLI, S. – RIZZI, A., Unsupervised Matching of Visual Landmarks for Robotic Homing Using Fourier-Mellin Transform, *Robotics and Automation*, **40**, (2002), pp. 131–138.

[3] DAVISON, A. J. – MURRAY, D. W., Simultaneous Localization and Map-building Using Active Vision, *IEEE Trans. Pattern Analysis and Machine Intelligence*, **24**, no.7, (2002), pp. 865–880.

[4] DESOUZA,G. N. – KAK, A. C., Vision for Mobile Robot Navigation: A Survey, *IEEE Trans. Pattern Analysis and Machine Intelligence*, **24**, No.2, (2002), pp. 237-267.

[5] DISSANAYAKE, M. W. M. G. – NEWMAN, P. – CLARK, S. – DURRANT-WHYTE, H. F. – CSORBA, M., A Solution to the Simultaneous Localization and Map Building(SLAM) Problem, *IEEE Trans. Robotics and Automation*, **17**, No.3, (2001), pp. 229–241.

[6] GROMANN, A. – POLI, R., Robust Mobile Robot Localization from Sparse and Noisy Proximity Readings Using Hough Transform and Probability Grids, *Robotics and Autonomous Systems*, **37**, (2001), pp. 1–18.

[7] GUIVANT, J. E. – NEBOT, E. M., Optimization of the Simultaneous Localization and Map-building Algorithm for Real-time Implementation, *IEEE Trans. Robotics and Automation*, **17**, No.3, (2001), pp. 242–257.

[8] JENSFELT, P. – CHRISTENSEN, H. I., Pose Tracking Using Laser Scanning and Minimalistic Environmental Models, *IEEE Trans. Robotics and Automation*, **17**, No.2, (2001), pp. 138–147.

[9] KIDONO, K. – MIURA, J. – SHIRAI, Y., Autonomous Visual Navigation of a Mobile Robot Using a Human-guided Experience, *Robotics and Autonomous Systems*, **40**, (2002), pp. 121–130.

[10] KRöSE, B. J. A. – VLASSIS, N. – BUNSCHOTEN, R. – MOTOMURA, Y., A Probabilistic Model for Appearance-based Robot Localization, *Image and Vision Computing*, **19**, (2001), pp. 381–391.

[11] LI, S., Localization Along Routes, Based upon Iconic and Global Positioning System Information in Large-scale Outdoor Environments, *Advanced Robotics*, **15**, No.7, (2001), pp. 749–762.

[12] MATSUMOTO, Y. – IKEDA, K. – INABA, M. – INOUE, H., Visual Navigation Using Omnidirection View Sequence, *Proc. IROS99*, (1999), pp. 317–322.