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Method for Path Estimation by Image Matching

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Abstract. The conventional image registration method for localization has a drawback. Movements cannot be calculated without the recognition of landmark features in an image. Therefore, we developed an image-matching method focusing on appearance to detect the relative orientation between viewpoints using two omnidirectional images. We estimated the path based on the relative orientation of these images.

Keywords: Localization, Omnidirectional Image

1. Introduction

The use of three-dimensional maps and street view images has spread rapidly in the last decade [1]. A notable feature of these media is their ability to reflect reality. However, there is a restriction on the production of outdoor scenes using these media. For example, three-dimensional maps represent the shape of terrain, buildings, roads, and roadside equipment in outdoor scenes. Street views also provide images that are taken from the road. Studies have also been conducted on indoor three-dimensional map construction [2]. Other studies have developed a method for representing indoor architecture using images as a map. Image-based rendering (IBR) is a method for displaying an image of an indoor scene from different perspectives in virtual space [3]. Observations of positional inputs are indispensable when constructing IBR scenes. The main reason why indoor map use has not spread is the absence of a positioning system such as the global positioning system, which would facilitate the production of three-dimensional maps or street view images of indoor environments. One approach to solve this problem is based on robotics; it is known as simultaneous localization and mapping [4] [5]. This method recognizes landmarks (e.g., doors, lights, edges in scenes) in images acquired by a camera installed in the robot, which is used to achieve localization [6] [7] [8]. This method does not work when a feature such as a landmark cannot be recognized. Another approach is to allow the system to extract shape features around the robot, such as a landmark, from a point cloud acquired by a laser range scanner [9] [10]. However, the limit of distance measurement with a laser range scanner is restricted in this method.

We developed a localization method to use in places that cannot be measured with a laser scanner or that lack adequate landmarks. We focused on differences in appearance that could be attributed to variations in the image acquisition position. In our method, a robot moves and takes pictures, while the system detects the relative direction from two neighbouring images using image registration. Image registration was studied using a phase-only correlation method and a mutual information method [11] [12]. The drawback of these methods is that two images cannot be matched, when the images are different. To overcome this drawback, we adopted an approach of comparing phase information for each azimuthal direction. The system initially divides an omnidirectional image in the azimuth direction and extracts phase information in the elevation direction of each image. The system then compares phase information to detect the relative direction of the two images. This method made it possible to estimate the path of a robot moving in a large space or a space with no landmarks.

2. Path Estimation Method

Figure 1 shows configuration of robot. An omnidirectional camera is installed horizontally. Figure 2 shows the process flow of the path estimation method. System takes a picture of the surroundings appearance by the omnidirectional camera. The system then converts the omnidirectional image into a plane image where the longitudinal axis indicates the pitch angle and the horizontal axis indicates the azimuth angle. In the image-matching process, the system detects the difference between the azimuth angles in the two images and calculates the orientation angle from the position where one image moves toward the position of the next (θa and θb in Figure 2). The path estimation process estimates the path based on the relative azimuth of the points.

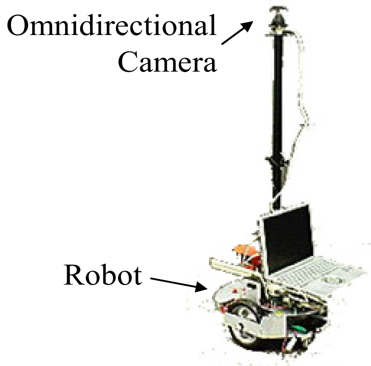
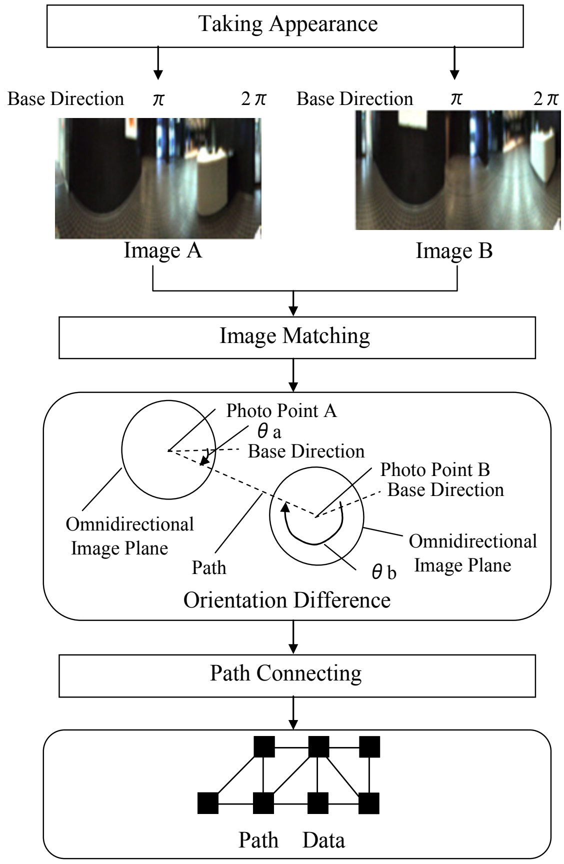


Fig. 1: Configuration of Robot



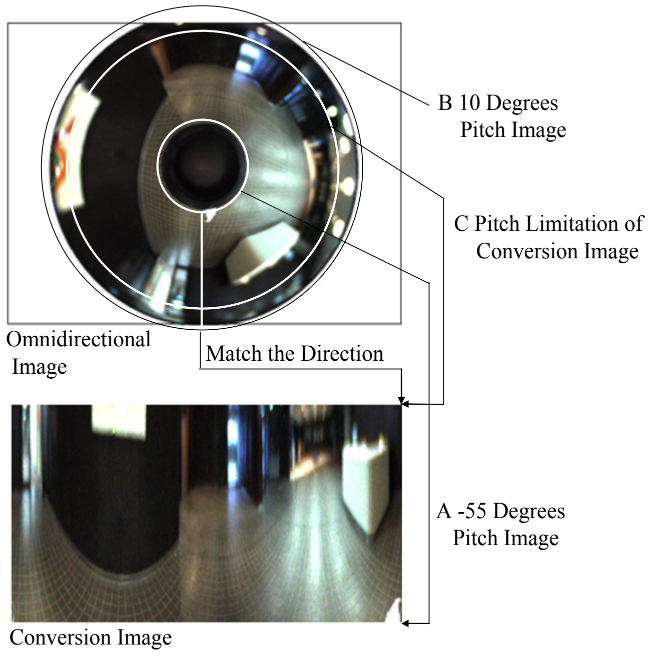


Fig. 2: Process Flow of Path Estimation Method. Fig. 3: Image Conversion Example.

2.1. Image Acquisition Method

A photograph is taken in the environment without moving objects such as persons to measure the structure of the indoor space. An omnidirectional camera is installed horizontally at a height of 1 m to ensure that the robot itself does not interfere with image capture. The robot is controlled remotely via wireless LAN.

Figure 3 shows an example of image conversion. The system converts an omnidirectional image into a plane image where the longitudinal axis indicates the pitch angle and the horizontal axis indicates the azimuth angle.

2.2. Image-Matching Method

Two images taken at separate points are characterized by the absence of parallax in the direction of a line that contains the points where the images are taken. We focused on this point and split each image in this direction, by comparing two images in that direction. However, appearance is not focused in an image taken by the omnidirectional camera, we compared not images but the phase information in the direction. Split images were calculated in the direction of the pitch by Fourier transformation. We compared phase information of split images in each azimuth direction. When phase information of split images were compared, the correlation in the images was the highest in the direction of a line containing the points where the images were taken. Figure 4 shows the results of image matching. Figure 4 shows the direction and pitch of each of the two axes for image A and image B. Spectral graphs show the Fourier transform value (1), the horizontal axis shows the direction, the vertical axis shows the order, and the pixel value indicates the power of the spectrum. The two images are matched in a direction connected by dotted lines. The system calculates the Normalized Cross-Correlation (2) between spectral graph A and spectral graph B. The system changes the shift number of graph B, and finds the shift number in which Normalized Cross-Correlation is maximized. If the shift number is s, this maximizes the correlation in Figure 4, Figure 5 shows the relationship between s and the position where images are taken. The angle between the directions of image A and image B is indicated by the shift number s.

$$F_k = \sum_{n=-\frac{N}{2}}^{\frac{N}{2}} I_n \, e^{-j\frac{2\pi}{N}kn} \qquad \text{-----------------------------(1)}$$

$$R = \frac{\sum_i \sum_j I_A(i,j)^2 \, I_B(i,j)^2}{\sqrt{\sum_i \sum_j I_A(i,j)^2 \times \sum_i \sum_j I_B(i,j)^2}} \qquad \text{------------------------(2)}$$

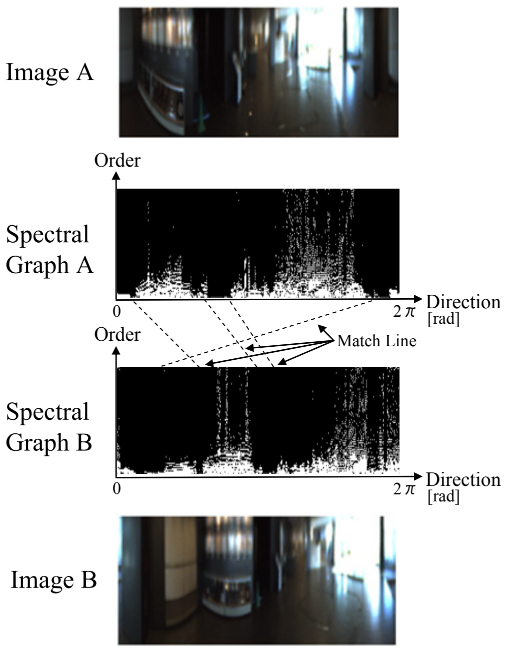


Fig. 4: Results of Image Matching

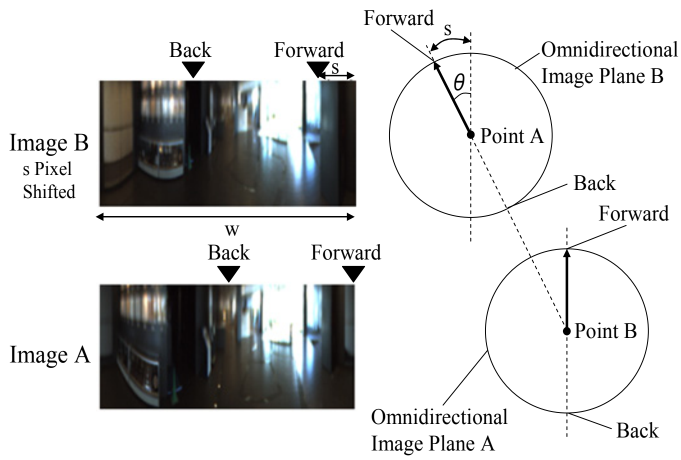


Fig. 5: Relationship Between Shift Number and Position

2.3. Path Connecting Method

We connected the path by applying open traverse surveying technology. Figure 6 shows the route connection method. In Figure 6, it is assumed that the positions of A and B are known already. Distance r is determined by the odometer of the robot. The position of C can be estimated using distance r, while the direction difference θ is obtained by matching image B and image C.

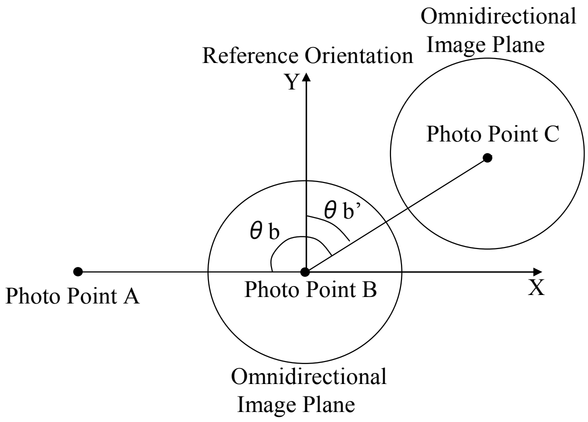


Fig. 6: Path Confecting Method

3. Path Estimation experiment

We carried out experimental evaluations of our method. We took 11 omnidirectional images using the robot. Figure 7 shows the image-matching results. The left images appear to be taken by the robot when moving straight. The system estimated the direction difference to be -15 degrees. The difference in appearance was because the position where the robot took the images was different. The right images appear to be taken by the robot when turning. There was a difference in appearance, but the matching result was correct because there were sufficient positions where the difference was low. Table 1 lists the matching results for each pair of images. We assumed that the error margin for the direction difference during IBR construction was less than 45 degrees because it succeeded in recognizing the corner when the IBR was displayed. The experimental matching results for 9 of the 10 pairs were accurate. Figure 8 shows the pair where the error was caused. The reason for the error was a vast difference in appearance. The connected path is shown in Figure 9. This shows the result of a connection only by a pair with a correct matching result. The matching result for the image 4–image 5 pair was incorrect, but the path was estimated using the correct matching result for the image 3–image 5 pair. The error margin of the estimated result was 0.77 m along a path with a total length of 17 m. The estimated path contained an error margin of 45 degrees or less, so the IBR constructed using the estimated path was a suitable guide to successfully recognize the corner.

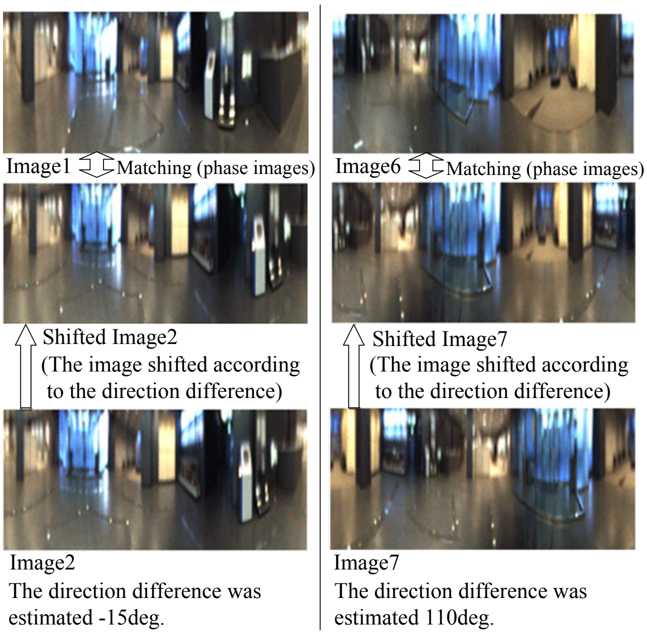


Fig. 7: Image-Matching Results.

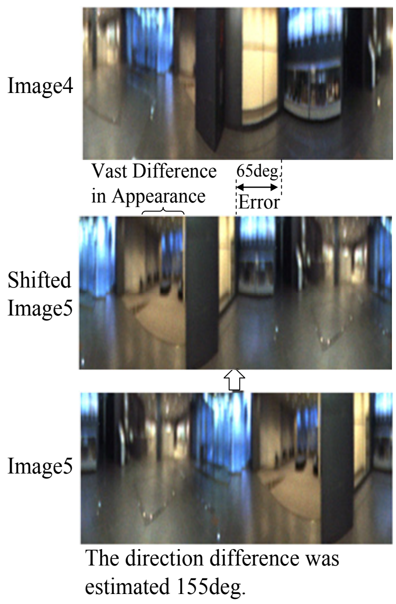


Fig. 8: Error Case

Table. 1: Image-Matching Results.

Image Pair	True [deg]	Estimation [deg]	Error [deg]	Available
0-1	0.0	0.0	0.0	○
1-2	0.0	345.0	-15.0	○
2-3	0.0	348.3	-11.7	○
3-4	0.0	0.0	0.0	○
4-5	90.0	155.0	65.0	×
5-6	0.0	6.7	6.7	○
6-7	90.0	110.0	20.0	○
7-8	0.0	353.3	-6.7	○
8-9	0.0	0.0	0.0	○
9-10	-39.8	339.2	19.0	○
3-5	90.0	80.0	-10.0	○

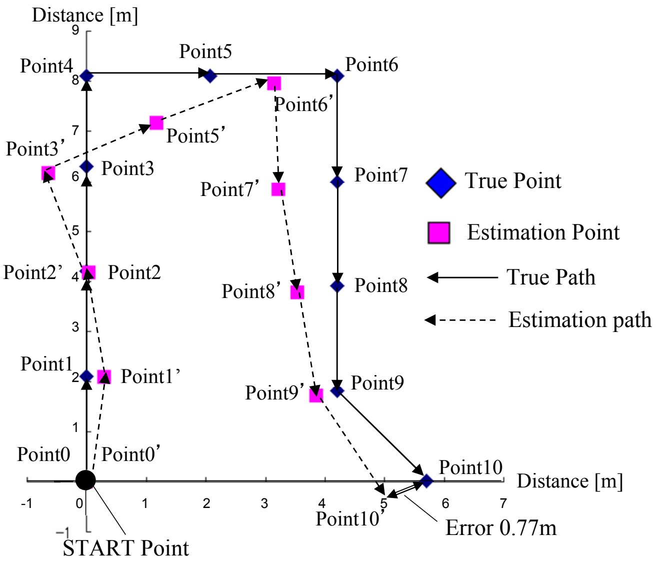


Fig. 9: Estimation Path

4. Conclusion

We developed an image-matching method to detect the relative orientation between the viewpoints of two omnidirectional images. The conventional image registration method for localization has a drawback. Movement cannot be calculated without recognizing landmark features in the image. The path cannot be estimated in a wide space measured using a laser range scanner. Our method allows paths to be estimated using only the images because our method does not require environmental landmarks and it does not use a laser range scanner. Our experiment demonstrated that it was possible to construct an IBR that was suitable for route guidance using paths estimated by our method. It shows that the IBR map construction in indoor environment without positioning system was enabled by our method. The remaining problem with our method is a match error by the differences in appearance, when there is distance between the positions where the robot took the images.

5. References

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