Navigation system for a mobile robot using an omni-directional camera

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Abstract

This study developed a self-localization system that uses landmarks and movement to pursue a moving object. Specifically, an omni-directional camera was adopted as a visual sensor and was installed on a robot.

The image from the omni-directional camera was processed to detect a landmark (an object), and the robot's distance from that landmark was then measured. These functions allowed the mobile robot to pursue a moving object. The measurement of distance based on the omni-directional image depends on the precise inclination of the camera. Consideration of this factor enabled the measurement of distance of relatively close objects with a high degree of precision.

In this study, the effectiveness of this system was investigated by various experiments evaluating the measurement of distance, the movement to pursuit a moving object, and self-localization. The robot demonstrated its ability to recognize a moving object and to measure its distance and its angle in relation to the object. Based on these abilities, the robot could successfully follow a moving object. The robot's ability to recognize its location was seen to be based on its ability to recognize certain landmarks, the functions of which are mentioned above.

1. Introduction

With the increase of the elderly population comes an increase in individuals who need attendant care. These increases will also bring about an increase in the burden of caregivers.

This study aimed to develop technology for a personal care robot that will reduce the burden of the caregiver. Specifically, an omni-directional camera was adopted as a visual sensor and was installed on a robot.

The image of the omni-directional camera was processed to detect a landmark (an object), and the robot's distance to that landmark was then measured.

Thus, a self-localization system that uses landmarks and movement to pursue a moving object were developed.

2. Omni-directional camera

2.1 Background of an Omni-directional camera

Fig. 1 shows the omni-directional camera. It can shoot a circumference of 360 degrees. Fig. 2 is an image that was shot by the omni-directional camera.

Fig. 1 The omni-directional camera

Fig. 2 Omni-directional image

2.2 Principle of the omni-directional camera

An omni-directional camera consists of a hyperboloidal mirror and an upward camera. It shoots the circumjacent environment that is reflected in the mirror. Thus, it acquires an omni-directional image (Fig. 3).

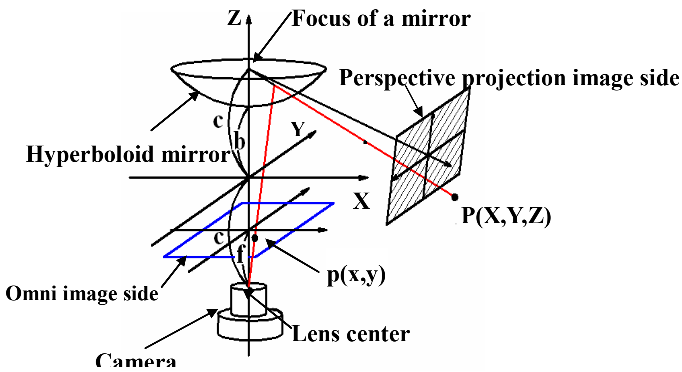

Fig. 3 Structure of visual system

The arbitrary point P(X,Y,Z) in 3-dimensional space corresponds with point p(x,y) on the omni-directional image.

The relation can be expressed by expression (1).

$$x = X \times f \times \frac{(b^2 - c^2)}{(b^2 + c^2)Z - 2bc\sqrt{X^2 + Y^2 + Z^2}}$$
$$y = Y \times f \times \frac{(b^2 - c^2)}{(b^2 + c^2)Z - 2bc\sqrt{X^2 + Y^2 + Z^2}} \quad (1)$$

3. Detecting a landmark

The image processing applied to the image from the omni-directional camera (Fig. 4) used color information.

When detecting a landmark by use of color information, an RGB color model has to discriminate a color based on three values (R, G, and B). This makes detection challenging. However, a HSV color model is able to discriminate a color by one value. Accordingly, the RGB color model was converted to a HSV color model, and thereby detected the landmark by HSV values.

When detecting a landmark using HSV values, some noise is present. In such cases, the image processing removes the noise. Also, it discriminates an object using labeling.

Fig. 4 shows an omni-directional image and Fig. 5 shows how it was processed by means of image processing.

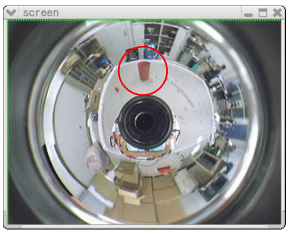

Fig. 4 The picture before the image data processing

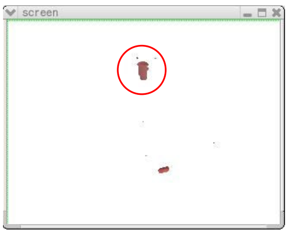

Fig. 5 The picture after the image data processing

4. Measuring the distance to the landmark

The distance between the omni-directional camera and a landmark was measured by means of the omni-directional image. This study derived relations between the distance on the omni-directional image and the real distance. And it directly calculated the distance from the image.

Concretely speaking, we experimentally derived relations between the distances on an omni-directional image and real distances. From this experiment result, we were able to derive relations between the distance of an image in the directions of 0, 45, 90, 135, 180, 225, 270, and 315 degrees and the real distance. But the system could not measure distances in between these directions because it only derived relations of 45 degree intervals. Therefore, it interpolated the distance using an interpolating spline, and was able to derive a relation expression that calculated real distances. Fig. 6 shows a graph of the relation expression.

The omni-directional camera was strapped into a tripod stand, and measured real distances. As a result, the value of the average error was 13[mm].

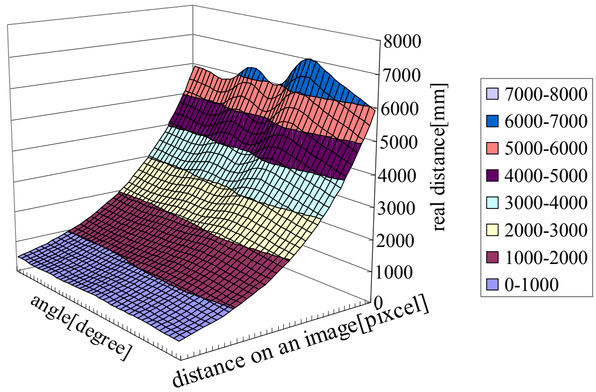

Fig. 6 The spline surface

5. Installing on a mobile robot

5.1 Mobile robot KITASAP2

In this study, we used a mobile robot that was fabricated in this laboratory. Fig. 7 shows a picture of the mobile robot. The robot we adopted has three wheels. The two front wheels have independent drives while the rear wheel is free.

The following devices were adopted in the mobile robot.

- PC
- H8 microcomputer
- Sensor
  - ① Omni-directional camera
  - ② Encoders

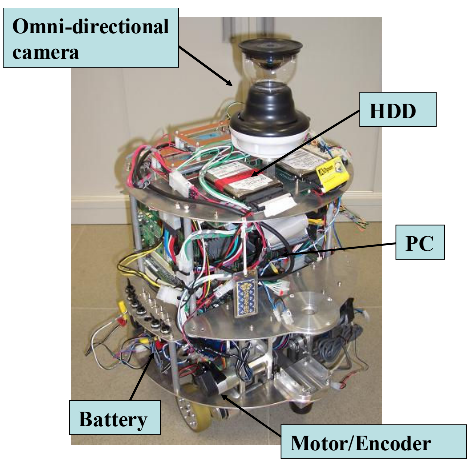

Fig. 7 The mobile robot

5.2 Compensation of slippage by an incline

The omni-directional camera was installed in the mobile robot, and it measured distance as before. While the error in the case described above was 13[mm], the error in this case was 53.52[mm].

It is thought that cause of this greater error was the slippage on the incline that occurred when we installed the camera. Therefore, we revised the slippage.

In Fig. 8, the dashed line indicates the direction in which the omni-directional camera inclines, and the continuous line is the horizontal.

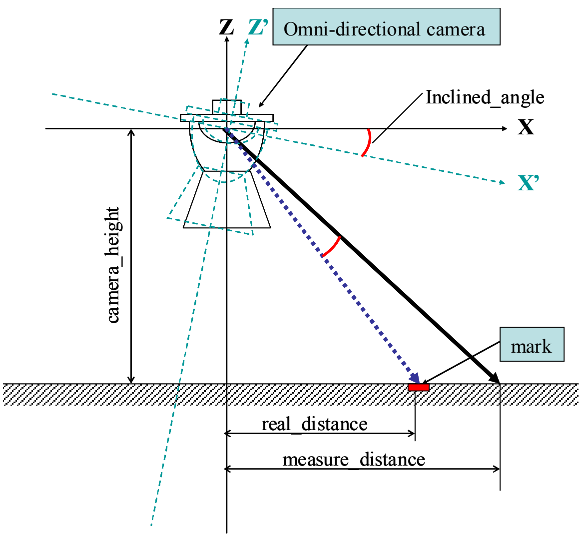

Fig. 8 Inclinations of the omni-directional camera

Assuming the height of the camera is given, we can express the incline (the angle between arrows) in the following expression.

$$inclined\_angle = tan^{-1}\left(\frac{camera\_height}{measure\_distance}\right) - tan^{-1}\left(\frac{camera\_height}{real\_distance}\right) \quad (2)$$

We calculated the inclines of each direction from this expression (2), and revised the data using calculated inclines and expression (1).

The average error before revising was 53.32[mm], while that after revising was 9.72[mm]

6. Following a mobile object

Applying the above-described detection of a landmark and measurement of the distance to the landmark, we attempted to have the mobile robot follow a mobile object. Mobile robots calculate the movement course by measuring distance and angle information. Here, we explain the calculation method of the movement course of the robot. The mobile robot calculates a circle such that the direction of the robot's progress is a tangent line and the circle passes through the position of the object (Fig. 9)

This circle is unique. Therefore, the mobile robot assumes this circle as its movement course. The radius of this circle can be calculated with expression (3). By performing these calculations and movements repeatedly, we succeeded in having the robot follow a mobile object.

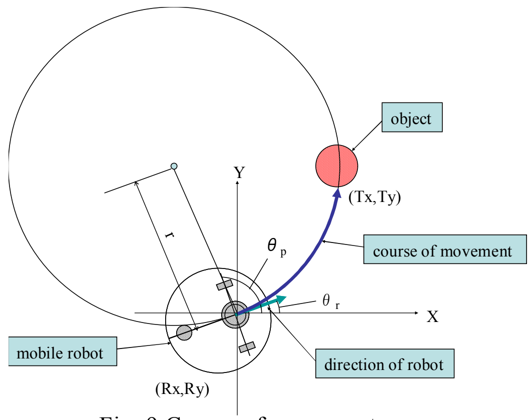

Fig. 9 Course of movement

$$r = \frac{(Tx - Rx)^2 + (Ty - Ry)^2}{2\{\cos\theta_p (Tx - Rx) + \sin\theta_p (Ty - Ry)\}} \quad (3)$$

7. Self-localization

We applied the above-described detection of a landmark and measurement of the distance to the landmark in creating a self-localization system. Here, I explain the method of self-localization. The mobile robot calculates circles using the distance to the landmark (Fig.10). The point where three circles cross becomes its self-position.

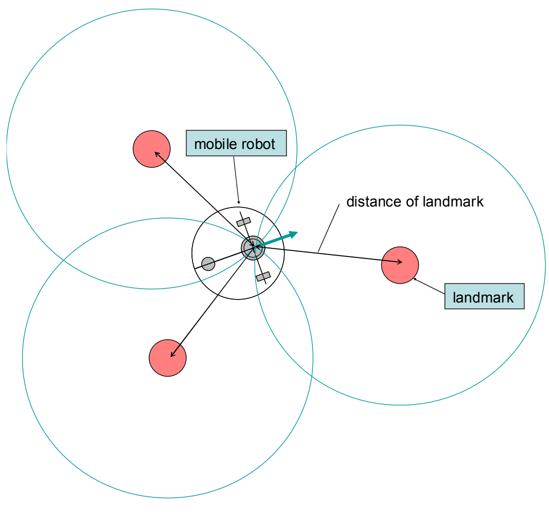

Fig.10 Self-localization

In addition, we tested self-localization in an environment such as that shown in Fig.11. We moved the robot from the A spot (-500,-500) to the B spot (500,-500) and moved it again afterwards to the A spot (-500,-500). During movement, we tested the robot's self-localization. The result is shown in Fig. 12.

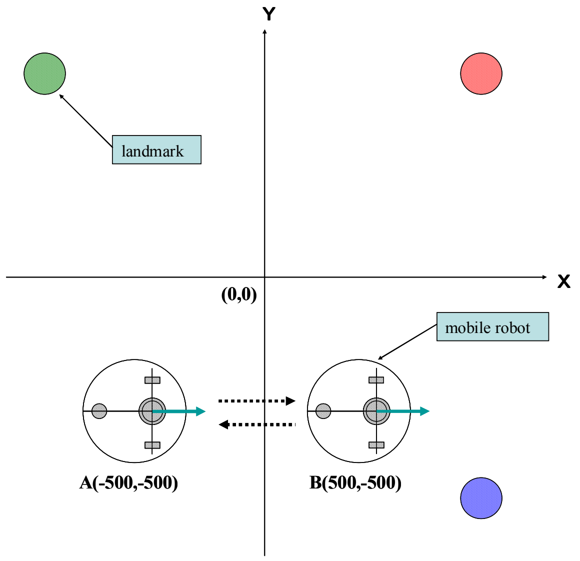

Fig. 11 Result of experiment

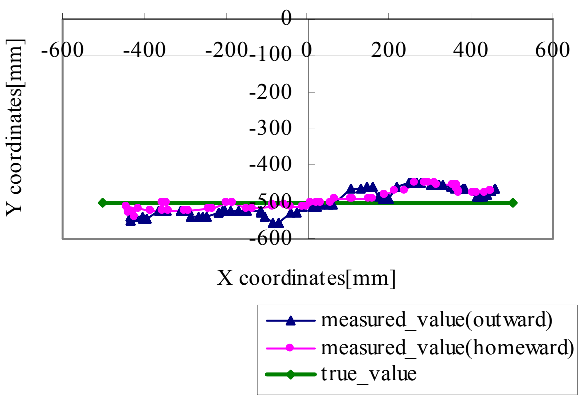

Fig. 12 Result of experiment

8. Conclusion

In this paper, as elements of a navigation system for a mobile robot using an omni-directional camera, we developed systems for following a mobile object and for self-localization using a landmark. The robot demonstrated its ability to recognize a moving object and to measure its distance and its angle in relation to the object. Based on these abilities, the robot could successfully follow a moving object. However, the precision decreased sharply when the distance of the landmark became remote.

Therefore in the future, we will aim at improving self-localization. Concretely, in considering the shape of landmarks, the robot will be able to detect its position more precisely.

8. Acknowledgment

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References

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