Location estimation method using photoconductor diode and room lighting

Kanako Kinoshita*, Akihiro Itoa, Kenta Kagemotoa, Mizuho Kimuraa, Shiyuan Yanga

*Department of Electrical and Electronics Engineering, Kyushu Institute of Technology, Japan

*Corresponding Author: o108042k@mail.kyutech.jp

Abstract

It has been studied much about an indoor self-controlled mobile robot in recent years, and accurate own location presumption is needed for it. The one which exists in all places is made a landmark and the system that the location can be detected clearly easily is needed. Therefore a location estimation using two photodiodes and one ceiling light marker is proposed by this paper.

A GPS and a way by comparison with a landmark map are mentioned by own location presumption of a conventional robot. But if they were those ways, high cost and complicated processing are needed. Our location recognition is low in cost by this experiment and, becomes possible by easy calculation.

Two photodiodes and one ceiling light marker were used for an experiment. First the illuminance of one ceiling light falling plumb down is measured. We use two photodiodes from there and find the radius using the difference in the illuminance. Only the inclination of two photodiodes shifts a polar coordinates using directional total. A cosine theorem can find the angle from three sides of the triangle with which a point of two photodiodes and a point of one ceiling light falling plumb down were connected, so two polar coordinates of photodiode are desired.

Keywords: photodiode, LED light marker, indoor location detection.

1. Introduction

In recent years, automatic guided vehicles are usually used for transportation of equipment in hospitals, including production lines for automobiles and foods. It is often used mainly as a factory or hospital. However, if it becomes possible to let a person with disabilities move and move large luggage at home, it will be very convenient if people can help their daily life, it is essential for people's lives. For that purpose, it does not run only on a fixed course, but must run freely anywhere. And it have to recognize that own location accurately for a robot to run freely.

In this paper, we propose a self position estimation method using one indoor LED illumination and two photodiodes as a system for recognizing self position based on what exists in every place.

2. Principle of self position estimation using one indoor LED illumination and two photodiodes

The image of this research system is shown in Figure 2.1. Two photodiodes are attached to a robot that moves to find out where in the room it is, and the position is detected from the illuminance of one LED lighting.

Figure 2.1 Image diagram

2.1 The principle of illumination

The method of detecting the position by the photodiode and the LED illumination utilizes the change in illuminance with respect to the incident angle of light. In order to investigate the change in illuminance with respect to the
incident angle of light, we first describe the relationship between illuminance and distance.

When the size of the light source can be regarded as being sufficiently small, the illuminance is inversely proportional to the square of the distance from the light source.

Since the definition of light intensity $I$ is a light flux per unit solid angle

$$I = \frac{d\Phi}{d\Omega} \quad (2.1)$$

Since the definition of the illuminance is a luminous flux per unit area

$$E = \frac{d\Phi}{dA} \quad (2.2)$$

The definition of solid angle is the unit area on the sphere divided by the square of the radius

$$d\Omega = \frac{dA}{r^2} \quad (2.3)$$

Substitute Equation (2.1) (2.3) into Equation (2.2).

$$E = \frac{d\Phi}{dA} = \frac{d\Phi}{r^2 \cdot d\Omega} = \frac{I}{r^2} \quad (2.4)$$

Therefore, the inverse square law of distance with respect to illuminance is obtained.

$$\Phi_1 = \Phi_2. \text{ In the case of irradiating from an oblique direction, since the irradiated surface is cut when the cylinder is obliquely cut,}$$

$$A_2 = \frac{A_1}{\cos \theta} \geq A_1 \quad (\cos \theta \leq 1) \quad (2.6)$$

Can be expressed as. Since a larger area is incident with the luminous flux $\Phi_1 = \Phi_2$ than at the time of normal incidence, the illuminance $E_2$ is low. Therefore, the illuminance $E_2$ at the time of incidence from an oblique direction is

$$E_2 = \frac{\Phi_2}{A_2} = \frac{\Phi_1}{A_1} \cdot \frac{A_1}{\cos \theta} = E_1 \cos \theta \quad (2.7)$$

It is expressed like this. That is, the illuminance $E_2$ when incident from the $\theta$ direction is $\cos \theta$ times the illuminance $E_1$ when incident from the vertical direction. Therefore, it is possible to obtain the oblique incident light characteristic of illuminance.

From the inverse square law of the distance with respect to the illuminance and the oblique incident light characteristic, we derive the characteristic of illuminance distribution on the plane to be illuminated by the microscopic light source called cosine fourth law. First of all, as shown in Fig. 2.3, consider the illuminance $E_3$ of the distance $S_3$ which is directly under the light source by the point light source of the light intensity $I$ which uniformly emits light in all directions.

$$E_3 = \frac{1}{S_3^2} \quad (2.8)$$

It is like this. Subsequently, the illuminance $E_4$ at the incident angle $\theta$ at the distance $S_4$ from the light source is
\[ E_4 = \frac{I}{S_4} \quad (2.9) \]
\[ S_4 \cos \theta = S_3 \quad (2.10) \]

It is expressed like this. Therefore, the illuminance \( E_4 \) on the virtual plane is
\[ E_4 = \frac{I}{S_4} = \frac{I \cos \theta}{S_3} = E_3 \cos^2 \theta \quad (2.11) \]

It is expressed like this. Further, since this virtual plane is inclined by an angle \( \theta \) with respect to the actual plane, the illuminance \( E_\theta \) from the actual point light source is
\[ E_\theta = E_4 \cos \theta = (E_3 \cos^2 \theta) \cdot \cos \theta = E_3 \cos^3 \theta \quad (2.12) \]

It is expressed like this. However, it can be regarded as a light source having actual directionality as long as it can be regarded as a diffusion point light source having uniform light intensity \( I \) in all directions. Assuming that the light intensity in the direction of \( \theta = 0^\circ \) is \( I_3 \), the light intensity \( I_\theta \) in the direction of a certain angle \( \theta \) is
\[ I_\theta = I_3 \cos \theta \quad (2.13) \]

It is expressed like this. Therefore, the illuminance distribution of the surface to be illuminated by the microscopic light source is further multiplied by \( \cos \theta \) with respect to the expression (2.11)
\[ E_\theta = E_3 \cos^4 \theta \quad (2.14) \]

Such a theoretical formula is derived. Using this cosine fourth law, illuminance can be predicted by the position of the robot.

### 2.2 Proposal of position detection by illuminance

The principle of detecting the position by illuminance will be described next. Place two photodiodes horizontally as shown in Figure 2.4, and install a compass between there.

![Figure 2.4 Principle chart for detecting position from illuminance](image1)

Let \( Z \) be the distance from the light source to the origin and \( R_1 \) and \( R_2 \) be the distances from the origin to \( P_1 \) and \( P_2 \), respectively. When the illuminance immediately under the light source is \( E_{max} \) from the expression (2.14), the illuminance of \( P_1 \) and \( P_2 \) is
\[ E_i = E_{max} \cos^4 \theta \quad (i = 1, \ 2) \quad (2.15) \]

It is expressed like this. When this expression is rewritten
\[ \theta = \cos^{-1} \left( \sqrt{\frac{E_i}{E_{max}}} \right) \quad (2.16) \]

It is expressed like this. Here, since \( \theta \) is an angle formed directly below the light source and \( P_i (i = 1, \ 2) \) from the light source
\[ R_i = Z \tan \theta \quad (i = 1, \ 2) \quad (2.17) \]

It is expressed like this. Substituting equation (2.16) into equation (2.17)
\[ R_1 = Z \tan \left\{ \cos^{-1} \left( \frac{E_1}{E_{max}} \right) \right\} \quad (2.18) \]
\[ R_2 = Z \tan \left\{ \cos^{-1} \left( \frac{E_2}{E_{max}} \right) \right\} \quad (2.19) \]

It is expressed like this. Therefore, the distance between the photodiode and the origin can be obtained from the illuminance and the distance from the light source to the origin.

Next, a method of obtaining coordinates will be described. First, the corner of the room whose position is to be estimated is taken as the center of the coordinates. Then, parallel movement is performed so that the center of the coordinates is directly under the light source. Since we want to estimate the position, install a photodiode at arbitrary two points and measure the inclination \( \theta \) with the azimuth meter. In this state it is difficult to determine the coordinates of \( P_1 \) and \( P_2 \). Therefore, as shown in Fig. 2.5, the coordinate axis is inclined by the same angle as \( \theta \) measured with the azimuth meter. Then, the straight line connecting the two photodiodes is always parallel to the Y axis, and it is classified into the three cases in Figure 2.6.

![Figure 2.5 Coordinates rotated using an azimuth meter](image2)
\( \angle P_1, \angle P_2 \) are obtained by the cosine theorem, and divided into three cases according to the magnitude relation with respect to \( \frac{\pi}{2} \). From the cosine theorem

\[
\angle P_1 = \cos^{-1} \frac{R_1^2 + L^2 - R_2^2}{2R_1L} \quad \text{(2.20)}
\]

\[
\angle P_2 = \cos^{-1} \frac{R_2^2 + L^2 - R_1^2}{2R_2L} \quad \text{(2.21)}
\]

It is expressed like this.

In the case of (a)

\[
\theta_1 = \frac{\pi}{2} - \angle P_1 \quad \text{(2.22)}
\]

\[
\theta_2 = \angle P_2 - \frac{\pi}{2} \quad \text{(2.23)}
\]

In the case of (b)

\[
\theta_1 = \frac{\pi}{2} - \angle P_1 \quad \text{(2.24)}
\]

\[
\theta_2 = 2\pi - \left( \frac{\pi}{2} - \angle P_2 \right) = \frac{3}{2}\pi + \angle P_2 \quad \text{(2.25)}
\]

In the case of (c)

\[
\theta_1 = 2\pi - \left( \frac{\pi}{2} - \angle P_1 - \frac{\pi}{2} \right) = \frac{5}{2}\pi - \angle P_1 \quad \text{(2.26)}
\]

\[
\theta_2 = 2\pi - \left( \frac{\pi}{2} - \angle P_2 \right) = \frac{3}{2}\pi + \angle P_2 \quad \text{(2.27)}
\]

It is expressed like this. Further, coordinates can be obtained by translating the axis of the room to the corner of the room according to the drawing.

3. Experiment

3.1 Verification of accuracy when placed parallel to north

Consider the case where the photodiodes are connected by a straight line and are parallel to the Y axis. In addition, since the left and right judgment with reference to the Y axis cannot be made with this calculation method, it is assumed that it is on the right side from the Y axis.

3.1.1 Experimental method

For LED lighting, four infrared LED lights were handled as one light source. We placed two photodiodes parallel to the north, with the floor being 180 cm away from there. Figure 3.1 (a) shows the positional relationship between the light projecting unit and the light receiving unit. Figure 3.1 (b) shows the positional relationship between the measuring point and the two photodiodes. Two photodiodes were placed parallel to the Y axis at intervals of 20 cm, such as \((X, Y) = (0, 50), (0, 30)\), and measured from 0 to 50 cm in the X axis direction.
3.1 Experimental result

The position where two photodiodes are actually placed is the theoretical value, and the position obtained by the calculation is the measured value. The theoretical values and measured values obtained are shown in Figure 3.2.

3.1.3 Discussion

Although it was possible to specify the approximate location from the experimental results, it was found that the error increases as the value of the Y axis increases. However, when obtaining the polar angle, the error when \((X, Y) = (20,10), (20,-10)\) is about 0.1\%. But the error when \((X, Y) = (50,50), (50,30)\) was about 0.1 to 0.3\%. This is because angles are calculated using the radius calculated from illuminance, so it is considered that the angle depends on the value including the error at the time of calculating the radius. From this result, it was found that, even with a slight error at the beginning, the error increases as calculation is performed using the value including the error, and a large deviation occurs as the final position.

Also, although there are places where values are not obtained in some places, it can be considered that the value of the angle itself can’t be obtained due to the fact that the angle error has become large as described above. When examining \((X, Y) = (0,30), (0,10)\), the angle is obtained using the cosine theorem, but since the obtained value exceeds the range of -1 to 1, No value was obtained. However, as we looked at only the values, we found that we could not estimate the position unless the accuracy of the obtained illuminance is very high as approaching the Y axis since we did not exceed the boundary only slightly.

3.2 Verification of accuracy when arbitrarily placed

We will verify the case where two photodiodes are arbitrarily placed. Also calculate assuming that it is on the right side of Y axis again this time too.

3.2.1 Experimental method

Similar to the previous experiment, LED lighting treated four infrared LED lights as one light source. Two photodiodes were arbitrarily placed with the floor being about 180 cm away therefrom, and the compass module was placed therebetween and the angle was measured. Figure 3.3 (a) shows the positional relationship between the light projecting unit and the light receiving unit. Also, in order to make the length between the two photodiodes 20 cm, place the photodiode as shown in Fig. 3.3 (b).
3.2. Experimental result

The position obtained by arbitrarily placing two photodiodes is the theoretical value and the position obtained by calculation is taken as the measured value. The theoretical values and measured values obtained are shown in Figure 3.4. Although it was planned to obtain by substituting the value obtained from the compass module, the magnetic field was always unstable because it was indoors, and it was impossible to obtain a stable value. For this reason, measurement was limited to 30 degrees and 330 degrees this time.

3.2.3 Discussion

Experimental results show that there is variation in accuracy. For example, the error in the case of \((X, Y)=(10, -20), (20, 0)\) is about 2 to 3 cm, the error in the case of \((X, Y)=(10, 40), (20, 20)\) is about 15 cm. However, since the relative error of the value of the illuminance obtained this time is all less than 0.1%, it can be said that there is a problem with the calculation method. When we calculate the radius from the illuminance of the theoretical value, since the error is about 0.1 cm to 5 cm, as mentioned in 5.1.3, even with a small error at the beginning, using the value including the error As the calculation was performed, the error became large, and it is considered that a large deviation occurred as the final position.

Also, as in the case described in 5.1.3, it can be considered that the value of the angle itself cannot be obtained due to the fact that the error of the angle becomes large as well as the point where the value is not obtained. From the result of this time it was found that the position of the polar coordinate after shifting the axis by the same as the inclination of the photodiode straight line can not be estimated unless the accuracy of the obtained illuminance is very high as approaching the Y axis.

Regarding the fact that the compass module could not be used, it is unavoidable that it will be unstable if it is indoors due to the nature of the compass, so it is considered necessary to use a calculation method that does not use compass in the future.

4. Conclusions

In some cases, the position can not be detected by the calculation method of this research system, but rough position can be detected in almost all cases. However, as can be seen from the results in Fig. 3.2 and Fig. 3.4, the accuracy of position detection is not highly accurate because there are variations. The reason for such a result is considered to be mainly in the calculation method. In this calculation method, the radius is obtained from the illuminance obtained as described in Chapter 2, and the angle is obtained using the radius. Here, although some errors occur, it is calculated from the radius including the error and the radius depending on the radius including the error at the time of further obtaining the coordinates, so the error will inevitably increase by any means.

References
