The Development of an Indoor Positioning System Using Incident Angle Detection of Infrared Emitters

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Abstract

In this paper, a new indoor positioning system based on incident angle measurement of infrared lights has been suggested. Though there have been various researches on indoor positioning methods using vision sensor or ultrasonic sensor, they have not only advantages, but also disadvantages. To minimize the disadvantages they have, this new method using incident angle of infrared light has been invented. In a new positioning system, there are three infrared emitters on fixed known positions. An incident angle sensor measures the angle differences between each two emitters. Measured angle differences determine a position. This method is available only inside the triangle which is composed of three emitters. Mathematical problems to determine the position with angle differences and position information of emitters has been solved. To solve the non-linear equations without prior position information, iterative linearization process has been used. Simulations and experiments have been implemented to show the performance of this new positioning system.

1 Introduction

Positioning is a major problem for mobile robots and autonomous vehicles. So, various positioning systems and algorithms have been researched to develop a navigation algorithm. GPS (Global Positioning System) is a precise absolute positioning system for the outdoors [1]. But, several indoor absolute positioning systems have been researched. The ultrasonic positioning system is very similar to GPS [2]. It measures distances from emitters to a measuring point. Then it solves the equations to determine its position. Since ultrasonic waves are much slower than electromagnetic waves, it is easier to count the spent time that diffused waves need to reach the measuring points than it does for GPS. However, waves radiated from other emitters interfere with each other. Thus, only one emitter can radiate ultrasonic waves at a time. Since all the transmitters radiate their waves by turns, it takes more time to measure all the distances from different transmitters.

An absolute position measurement system based on incident angle detection of infrared light is proposed [3]. Infrared light sources are mounted on a robot as markers. Then an observation agent mounted on a ceiling detects incident angles of infrared light emitted from markers. Though much infrared light is also contained in sunlight, it is rejected using filters. Emitters and a receiver use the same carrier frequency. And all the other frequencies are filtered out while passing the bandwidth filter.

In this paper, an absolute position measurement system based on incident angle detection of infrared light is proposed. Three infrared light sources are mounted in fixed positions as emitters. And three infrared incident angle sensors measure the incident angles of the infrared light from each of the three emitters. Then anyone who tries to measure their position can estimate their absolute position without external assistance.

2 Mathematical Problems of the System

Consider three points. A$(0,0)$ point is the origin, B$(x_2,0)$ point is on the x-axis, and the C(x_1,y_1) point is a point on the upper part of the right-half plane. Assume that all the coordinates of the three points are given as shown in Fig. 1. The relative

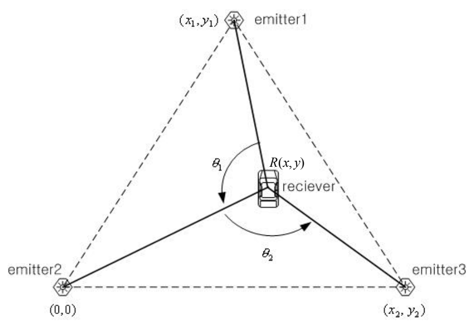

Fig. 1 Concept of new positioning system

position R(x, y) to the origin can be determined.

First, we can obtain the following equations to determine the position with given angle differences, θ_1 and θ_2. θ_1 is calculated by using an inner product of $\overrightarrow{RA}$ and $\overrightarrow{RC}$. And also, θ_2 is solved by using it for $\overrightarrow{RA}$ and $\overrightarrow{RB}$.

$$\overrightarrow{RA} \bullet \overrightarrow{RC} = |\overrightarrow{RA}| \bullet |\overrightarrow{RC}| \cos\theta_1 \quad (1)$$
$$\overrightarrow{RA} \bullet \overrightarrow{RB} = |\overrightarrow{RA}| \bullet |\overrightarrow{RB}| \cos\theta_2 \quad (2)$$

To solve the equations (1), (2) about θ_1 and θ_2:

$$\theta_1 = \cos^{-1}\frac{x^2 - x_1 x + y^2 - y_1 y}{\sqrt{x^2+y^2} \bullet \sqrt{(x_1-x)^2+(y_1-y)^2}} \quad (3)$$
$$\theta_2 = \cos^{-1}\frac{x^2 - x_2 x + y^2}{\sqrt{x^2+y^2} \bullet \sqrt{(x_2-x)^2+y^2}} \quad (4)$$

Equations (3), (4) are linearized by using Fourier Transformation.

$$\delta\theta_1 = \left.\frac{\partial f_1}{\partial x}\right|_{\substack{x=x_0\\y=y_0}} \delta x + \left.\frac{\partial f_1}{\partial y}\right|_{\substack{x=x_0\\y=y_0}} \delta y + H.O.T.'s \quad (5)$$
$$\delta\theta_2 = \left.\frac{\partial f_2}{\partial x}\right|_{\substack{x=x_0\\y=y_0}} \delta x = \left.\frac{\partial f_2}{\partial y}\right|_{\substack{x=x_0\\y=y_0}} \delta y + H.O.T.'s \quad (6)$$

Where (x_0, y_0) is the point of linearization, $H.O.T.'s$ represents the higher-order terms in the expansion, and f_1 and f_2 are the functions as follows:

$$f_1 = \cos^{-1}\frac{x^2 - x_1 x + y^2 - y_1 y}{\sqrt{x^2+y^2} \bullet \sqrt{(x_1-x)^2+(y_1-y)^2}} \quad (7)$$
$$f_2 = \cos^{-1}\frac{x^2 - x_2 x + y^2}{\sqrt{x^2+y^2} \bullet \sqrt{(x_2-x)^2+y^2}} \quad (8)$$

Finally the equation (9) is obtained in representation of vectors as follows:

$$\underline{\theta} = \underline{\theta}_0 + P\delta\underline{r} + H.O.T.'s \quad (9)$$

where $\underline{\theta}_0$ is the initial value of $\underline{\theta}$,

$$\underline{\theta} = \begin{pmatrix}\theta_1\\ \theta_2\end{pmatrix}, \quad \delta\underline{r} = \begin{pmatrix}\delta x\\ \delta y\end{pmatrix},$$

and

$$P = \left.\begin{pmatrix}\dfrac{\partial f_1}{\partial x} & \dfrac{\partial f_1}{\partial y}\\ \dfrac{\partial f_2}{\partial x} & \dfrac{\partial f_2}{\partial y}\end{pmatrix}\right|_{\substack{x=x_0\\y=y_0}}$$

Assuming that the rows of P are linearly independent, equation (9) can be solved by inversion of the P matrix:

$$\delta\underline{r} = P^{-1}\delta\underline{\theta}, \quad (10)$$

with error $P^{-1}(H.O.T.'s)$.

When measurements from more than 3 emitters are available, the least-squares solution is

$$\delta\underline{r} = (P^T P)^{-1} P^T \delta\underline{\theta}. \quad (11)$$

With knowledge of the position error $\delta\underline{r}$, the actual position is determined as

$$\underline{r} = \underline{r}_0 + \delta\underline{r} \quad (12)$$

Assuming no prior position information, the iterative linearization process will be initialized at a fixed point in the triangle consisting of the given three points.

3 Simulations

In order to examine the performance of the positioning algorithm, Matlab 6.1 is used.

Consider the process shown in Fig. 3. The three points are $(0,0)$, $(0,2)$, and $(1, \sqrt{3})$ respectively so that they compose a regular triangle. The fixed initial point to determine the position without prior position information is $(1, 1\sqrt{3})$. So, that is the centroid of the given regular triangle shown in Fig. 2.

First, test the algorithm without the prior position information. To determine the exact position without it, iterative calculations are necessary. Using the iterative linearization process based on equation (12), position values are converged very fast, as shown in Fig. 2. The angle differences used in this simulation are 80 and 130 degrees. The position values are converged within 4 steps with very small errors.

Secondly, test the algorithm along the path, not a point. The test path is a horizontal straight line passing through the centroid in the range of $0.5 \le x \le 1.5$. In order to simulate the algorithm, angle differences θ_1 and θ_2 of the test path are

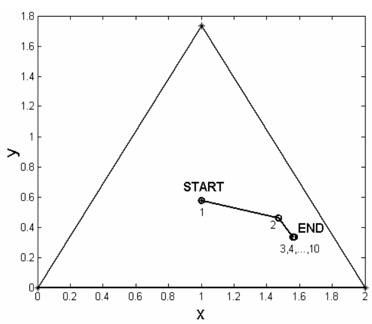

Fig. 2 The iterative linearization process

needed. Fig. 3 hows the result of the simulation Fig. 4 is the result of the curvature test.

4 Experimental and Result

To determine the incident angle, current passing through the sensor has to be measured. The incident angle sensor is composed of two photodiodes. And the incident angle is determined by two current values from each photodiodes as follows:

$$\text{ANGLE} = \frac{a-b}{a+b} \times 0.012\,[\text{deg}] \qquad (13)$$

where a and b are output currents from the two photodiodes.

The picture of the incident angle sensor (HI-M600H3-2) and its characteristic is shown in Fig. 5. It detects tuned signals at 32kHz. In the range of $\pm 45\,[\text{deg}]$, the value of the incident angle from the sensor is absolutely linear.

Figure 6 shows the circuit to convert the current value to voltage value. The following relation is satisfied in the circuit:

$$V_0 = -I \times R \qquad (14)$$

where V_0 is the output voltage, and I is current from photodiode.

To measure the incident angles of the infrared lights, it is very important to reject the interferences and to amplify the signal. Bandwidth filter rejects all the frequencies except the carrier frequency. Op-Amps amplify the signal to a suitable voltage level for an A/D converter.

Experiments have been implemented inside the regular triangle of 2.36m for each side length, since the intensity of the emitters and infrared LED has been limited and we have had difficulties in signal conditioning. Figure 7 is the system configuration for the test. The system consists of 3 emitters and 1 receiver. Each receiver has a slit. It forbids the surrounding signals to interfere. The receiver is rotated by using a 400 pulse stepping motor. Its angular rate is 360deg/sec. Therefore the proposed system can get position data with 1Hz resolution. If the angular rate of the motor and signal processing time is faster, we can get higher resolution data. Figure 8 shows the emitter and receiver systems.

For each test, 11 points and 9 points are selected on the straight and curved path and the mean data are calculated using data every 10sec.

As shown in Fig. 9, the experimental result is very similar to the simulation result in Fig. 3 except for the limitation of ranges. The ranges of x and y in the experiment has been limited is because of the emitting shape of the infrared LED. Most of all, the infrared LED is produced for remote

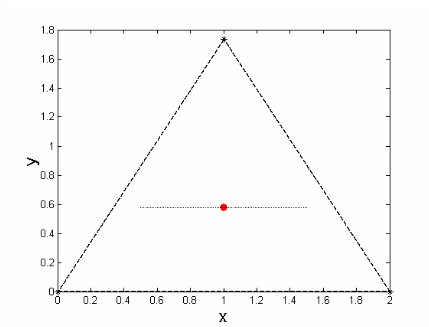

Fig. 3 Simulation result in a straight path

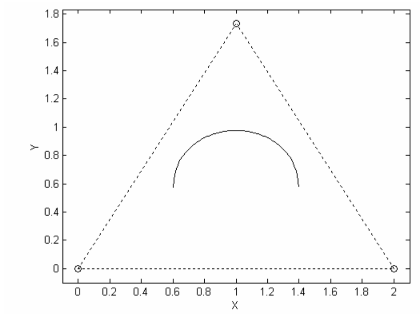

Fig. 4 Simulation result in a curve path

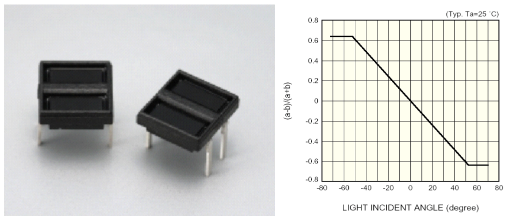

Fig. 5 Incident angle sensors

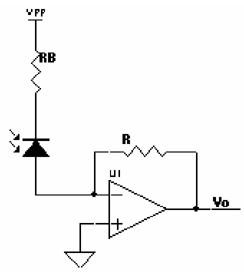

Fig. 6 Circuit to convert the currents to voltage

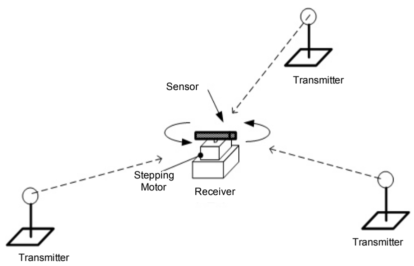

Fig. 7 System configuration for test

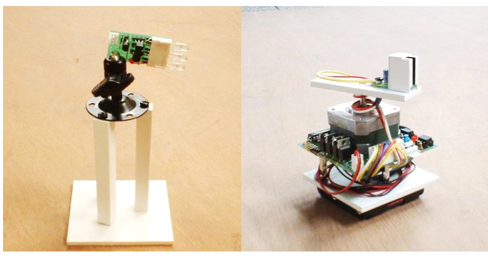

Fig. 8 Emitter and receiver

controllers or wireless communications. Therefore, the infrared light radiated from the LED is acutely focused on the center region.

Figure 10 shows the test result in a curved path.

5 Conclusions

In this paper, the new indoor positioning method using infrared lights has been suggested. Users are independent of the emitting devices so there is no limitation of the number of users provided in this positioning service. Since this method has no interactive process between emitters and receivers, the measuring time is less than any other positioning system. Mathematical problems necessary for the determination of the position havebeen derived. To solve these non-linear problems, an iterative linearization process has been used.

The algorithm to determine the position has been simulated and experimented. Results of the simulations were reasonable. Experiments have had many problems, such as the limitation of intensity of emitters and signal conditioning problems. Thus, the experiments have been implemented in a very bounded area, inside the regular triangle with 2.36m side length. However, the experimental result was acceptable.

This new positioning method can be applied to any indoor system that needs absolute position information. To apply this method to mobile robots or for industrial purposes, emitters should be improved to a more suitable form and signals from the sensors should be well-conditioned. More emitters can achieve more accurate positions using the Least Mean Square method.

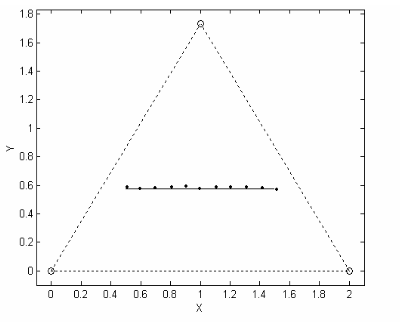

Fig. 9 Test results in a straight path

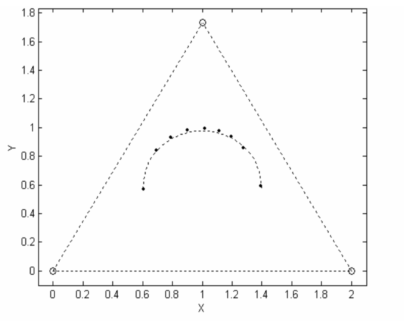

Fig. 10 Test results in a curved path

Acknowledgment

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