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Indoor Positioning System Based on Incident Angles 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 iuformation 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. The results of simulation were good. Since there existed problems of noise and signal conditioning, the experimented has been implemented in limited area. But the results were acceptable. This new positioning method can be applied to any indoor systems that need absolute position informations.**

I. INTRODUCTION

Positioning is an important problem to mobile robot. To measure an absolute position of a mobile robot, many methods using vision system or ultrasonic sensor system have been proposed.

To use vision system huge calculation must be done in short time. It is also installed as an external observer since it includes many devices and heavy equipments. Because it is an observation device, in order to estimate additional objects whole system must be changed. In addition, vision system is very prone to be affected by environment and obstacles around.

Ultrasonic positioning system is very similar to Global Positioning System(GPS). It measures distances from emitters to 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 for diffused wave to reach the measuring points than to do in GPS. But waves radiated from other emitters interfere each other. Thus only one emitter can radiate ultrasonic wave at a time. Since all the emitters radiate their waves by turns, it takes more time to measure all the distances from different emitters.

An incident angle sensor is very small and sensitive on the wavelength between 900 and 1000 nm, infrared region. Though much infrared light is also contained in sunlight, it is able to be rejected using filters. Emitters and a receiver use same carrier frequency. And all the other frequencies are filtered out while passing the bandwidth filter. Since the positioning system based on incident angle is not interactive, there is no limitation to the number of users.

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 position as emitters. And three infrared incident angle sensors measure the incident angles of the infrared light from each three emitters. Then anyone who tries to measure their position can estimate their absolute position without external assistance.

In section II, the concept of this new positioning system has been described, comparing with GPS. In section III, mathematical problems to determine the position have been solved. The proposed system is simulated by computer and experimented to investigate its performance. The results of them have been shown in section IV and V. Section VI has summarized the contents above and proposed future assignments.

II. CONCEPT FOR NEW POSITIONING SYSTEM

This new positioning system is based on the concept that is very similar to that of GPS. GPS measures the pseudoranges that are the distances from each satellites. And it computes the position with measured pseudoranges and position informations of each satellites shown in Fig. 1. In addition, real GPS needs one more satellites to determine the position because of clock bias.

In this paper we measure angle differences of each

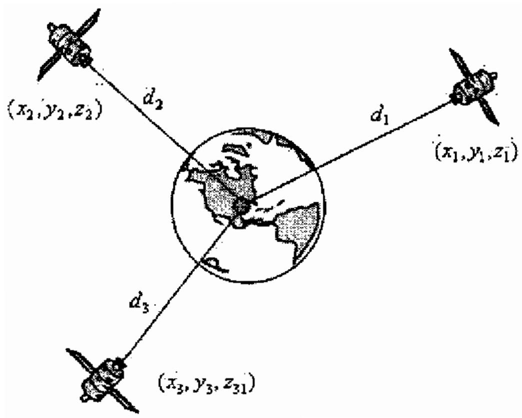

Fig.1 Concept of Global Positioning System

emitters and compute the position with measured angle differences and position informations of each emitters. This new positioning system is shown in Fig. 2.

Since GPS uses electromagnetic waves to measure pseudomages, it is very difficult to implement. All the satellites have to be synchronized and receiver has to count very small time differences in precious. Moreover GPS is not available indoor.

For absolute position measurement system, indoor satellites must be installed. However electromagnetic wave is too fast to use indoor or limited place. One of alternative methods is to use ultrasonic wave instead of electromagnetic wave. Ultrasonic wave is very suitable for indoor positioning system since it is very slower than electromagnetic waves. Therefore a research on indoor positioning system using ultrasonic sensors has been carrying out.

The most serious problem of the system using ultrasonic is interference among the ultrasonic emitters. Ultrasonic emitters radiate waves by turns, not at once because of interferences.

To solve all the matters listed above, another idea is suggested. We measure incident angles of the light diffused by each emitters instead of spent times to reach (to calculate distances). Infrared light is used for emission since it is invisible, very common currently, and distinguished from visible lights. Noise and disturbances from sun and indoor lights can be rejected using optical and electronic filters.

And this new positioning system is absolutely independent to all the emitters. In other words, there is no limitation to the number of users. The greatest advantage of GPS is just that GPS is not interactive. We do not have to send any information or any commands not only to satellites but to GPS stations. A GPS receiver takes the information from each satellites and compute the position by itself. Therefore there is no limitation on how many users can be served GPS at once.

III. Mathematical Problems

Consider three points. One is origin, another is on the x-axis, and the other is a point on the upper part of right-half

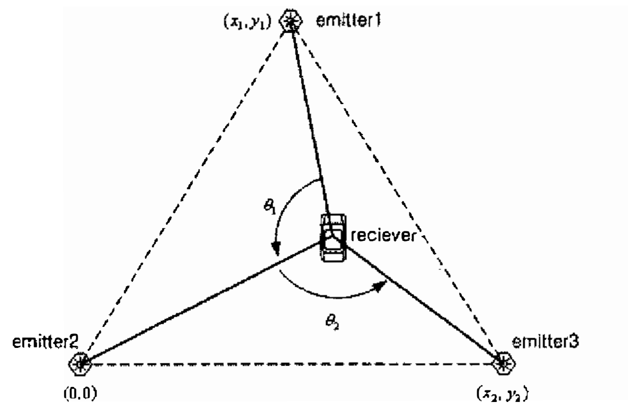

Fig.2 Concept of new positioning system

plane.

Assume that all the coordinates of three points are given as shown in Fig. 2. The relative position to the origin can be finally determined.

First we can obtain the following equations to determine position with given angle differences, θ_1 and θ_2.

$$\sqrt{x^2+y^2}\cdot\sqrt{(x_1-x)^2+(y_1-y)^2}\cos\theta_1 = x^2-x_1x+y^2-y_1y \tag{1}$$

$$\sqrt{x^2+y^2}\cdot\sqrt{(x_2-x)^2+y^2}\cos\theta_2 = x^2-x_2x+y^2 \tag{2}$$

Solve the equations (1), (2) about θ_1 and θ_2.

$$\theta_1 = \cos^{-1}\frac{x^2-x_1x+y^2-y_1y}{\sqrt{x^2+y^2}\cdot\sqrt{(x_1-x)^2+(y_1-y)^2}} \tag{3}$$

$$\theta_2 = \cos^{-1}\frac{x^2-x_2x+y^2}{\sqrt{x^2+y^2}\cdot\sqrt{(x_2-x)^2+y^2}} \tag{4}$$

Linearizing equations (3), (4) gives

$$\delta\theta_1 = \left.\frac{\partial f_1}{\partial x}\right|_{\substack{x=x_0\\y=y_0}}\delta x + \left.\frac{\partial f_1}{\partial y}\right|_{\substack{x=x_0\\y=y_0}}\delta y + H.O.T.'s \tag{5}$$

$$\delta\theta_2 = \left.\frac{\partial f_2}{\partial x}\right|_{\substack{x=x_0\\y=y_0}}\delta x + \left.\frac{\partial f_2}{\partial y}\right|_{\substack{x=x_0\\y=y_0}}\delta y + H.O.T.'s \tag{6}$$

where (x_0, y_0) is the point of linearization, $H.O.T.'s$ represents the higher-order terms in the expansion, and f_i is the function as follows.

$$f_1 = \cos^{-1}\frac{x^2-x_1x+y^2-y_1y}{\sqrt{x^2+y^2}\cdot\sqrt{(x_1-x)^2+(y_1-y)^2}} \tag{7}$$

$$f_2 = \cos^{-1}\frac{x^2-x_2x+y^2}{\sqrt{x^2+y^2}\cdot\sqrt{(x_2-x)^2+y^2}} \tag{8}$$

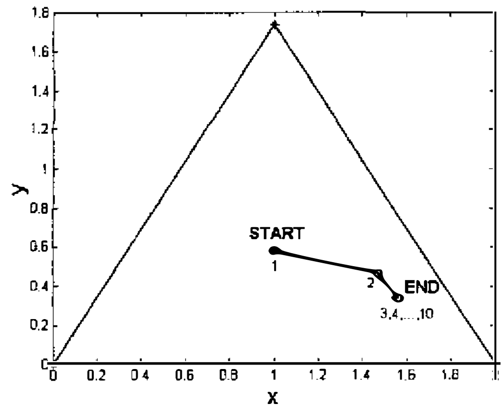

Fig.4 The iterative linearization process

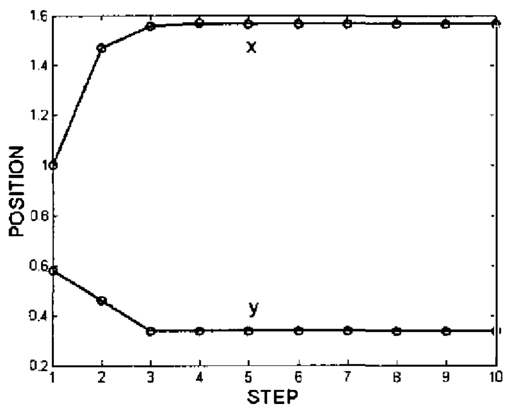

Fig.5 Convergence of the position values

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

$$\underline{\theta} = \underline{\theta}_0 + P\delta\underline{x} + H.O.T.'s \tag{9}$$

where $\underline{\theta}_0$ is the initial value of $\underline{\theta}$, $\underline{\theta} = \begin{pmatrix} \theta_1 \\ \theta_2 \end{pmatrix}$, $\delta\underline{x} = \begin{pmatrix} \delta x \\ \delta y \end{pmatrix}$,

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:

$$\delta\underline{x} = P^{-1}\delta\underline{\theta} \tag{10}$$

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

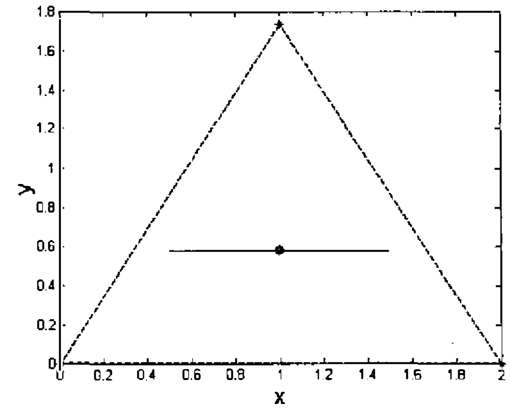

Fig.6 Test path for simulation

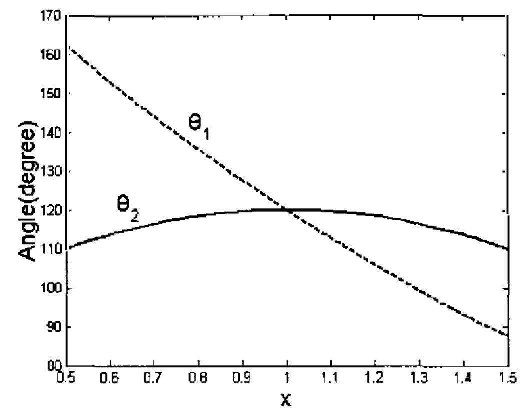

Fig.7 Variation of angle difference along the test path

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

$$\delta\underline{x} = \left(P^T P\right)^{-1} P^{-T}\delta\underline{\theta} \tag{11}$$

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

$$\underline{x} = \underline{x}_0 + \delta\underline{x} \tag{12}$$

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

IV. Simulations

In order to examine the performance of the positioning algorithm, simulation using computer is necessary. Consider the process shown in Fig. 4.

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

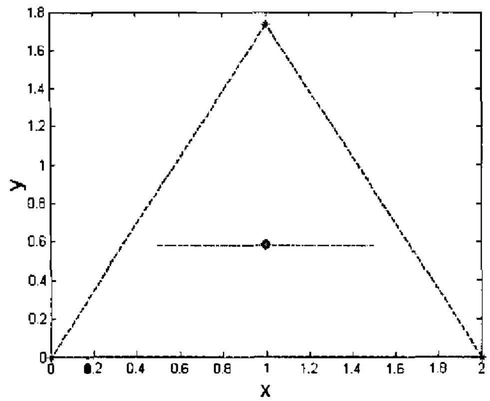

Fig.8 Simulation result

prior position information is $(1, 1/\sqrt{3})$, the centroid of the given regular triangle shown in Fig. 4.

First test the algorithm without prior position information. To determine the exact position without prior position information, iterative calculations are necessary. Using the iterative linearization process based on equation (12), position values are converged very fast as shown in Fig. 5. 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 $0.5 \geq x \geq 1.5$ as shown in Fig. 6. In order to simulate the algorithm, angle differences, θ_1 and θ_2 of the test path are needed.

Fig. 7 shows the angle differences along the test path.

Fig. 8 shows the result of the simulation for the data of Fig.7.

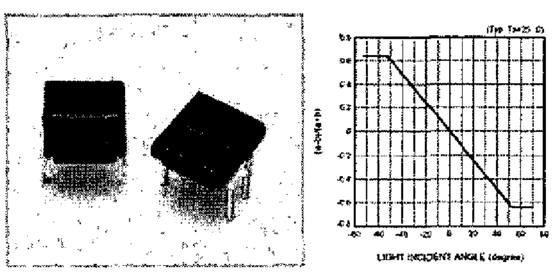

Fig.9 Incident angle sensors and their characteristic

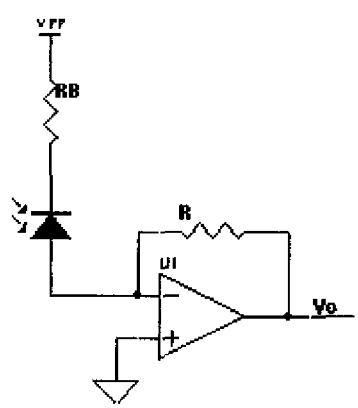

Fig.10 Circuit to convert the currents of photodiodes to voltage

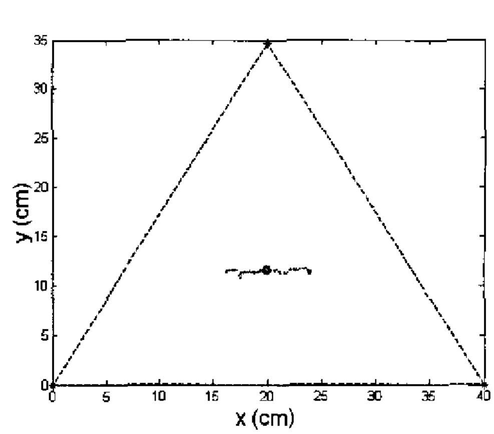

Fig.11 Experimental result

V. Experiments and Results

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.

$$ANGLE = \frac{a-b}{a+b} \times 0.012 \text{ [deg]} \tag{13}$$

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

The picture of the incident angle sensor and its characteristic is shown in Fig. 9. In the range of ± 50[deg] the value of incident angle from the sensor is absolutely linear.

Fig. 10 shows the circuit to convert the current value to voltage value. Following relation is satisfied in the circuit.

$$V_o = -I \times R \tag{14}$$

where V_o is 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-Amp's amplify the signal to an suitable voltage level for A/D converter.

Experiments have been implemented inside the regular triangle of 40cm side length, since intensity of the emitters, infrared LED, has been limited and we have had difficulties in signal conditioning.

As shown in Fig. 11, the experimental result is very similar to the simulation result in Fig. 8 except the limitation of ranges. The reason why the ranges of x and y in the experiment has been limited is because of emitting shape of the infrared LED. Most of all infrared LED is produced for remote controllers or wireless communications. Therefore the infrared light radiated from the LED is very focused on the center region.

VI. CONCLUSIONS AND FUTURE WORKS

In this paper, the new positioning method using infrared lights has been suggested. Users are independent to emitting devices so that there is no limitation of the numbers of the users provided this positioning service. Since this method has no interactive process, measuring time is less than any other positioning systems.

Mathematical problems necessary for determination of position has been derived. To solve these non-linear problems, iterative linearization process has been used.

The algorithm to determine the position has been simulated and experimented. Results of simulations were reasonable. Experiments have had many problems such as limitation of intensity of emitters and signal conditioning problems. Thus the experiments have been implemented in very bounded area, inside the regular triangle of 40cm side length. However the experimental result was acceptable.

This new positioning method can be applied to any indoor systems that need absolute position informations.

To apply this method to mobile robot or industrial purpose, emitters should be improved to suitable form and signals from the sensors should be well-conditioned.

More emitters can achieve more accurate positions using Least Mean Square method.

VII. ACKNOWLEDGEMENTS

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