Linear Positioning System based on IR Beacon and Angular Detection Photodiode Array

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***Abstract*—Following development of smartphones, wearable devices, and so on, it is possible to measure certain types of human behavior, such as the traffic flow of pedestrians. There is also a call to capture this data more efficiently. Existing indoor positioning methods pose problems in terms of cost and accuracy. The purpose of this study is to develop an indoor positioning method for obtaining data regarding the traffic flow of pedestrians. We propose an infrared (IR) beacon liner localization method based on a trigonometrical survey. In this paper, we evaluate the usefulness of the proposed method in relation to two experiments that were conducted using a prototype of the system. it was confirmed that the estimation accuracy was within the error of less than 0.7 m for static positioning and dynamic positioning estimation was along the movement of the IR beacon. This indicates that the proposed technique is useful for obtaining data about the traffic flow of pedestrians.**

I. INTRODUCTION

The development of mobile electronic devices (*e.g.*, the smartphone) and the daily use of web services have resulted in a number of trials to measure and understand people's individual activities. Furthermore, the use of such information in research is increasing, with the utilization of positional information being no exception. Although one might expect information about the indoor traffic flow of pedestrians to be used to help reduce congestion or improve layouts (especially in relation to retail stores), this area is failing to develop due to problems with accuracy and the costs of introducing such methods.

These days, the GPS positioning method is widespread. This technique cannot be used indoors, however, as the GPS signal is not strong enough. This fact informs a number of researches focused on indoor positioning techniques[1]–[6]. Specifically, there are three principal methods for measuring the traffic flow of pedestrians: (1) methods based on Wi-Fi signals, (2) methods using ultrasonic signals, and (3) methods using BLE (Bluetooth Low Energy). Localization based on Wi-Fi signals uses existing access points, which creates an advantage in terms of introduction costs; this method is affected, however, by a lack of the access point or electromagnetic waves reflection. Furthermore, the positioning error would result in several meters[7], [8]. Localization based on ultrasonic signals leads to fewer errors; however, it does not work well where a wide range is required, due to the attenuation of the signal. However, the estimation error on BLE would be decreased by 1 m each time a beacon is added to the system, mobile electronic devices must be used, which has to be installed on a moving object [9], [10]. Such a method increases the costs of repair and maintenance. Moreover, all these methods usually rely on the use of smartphones[11].

If we considered about both introduction costs and localization accuracy, the requirement can be deduced that pedestrian localization systems for retail stores, as the following: (1) the estimation error for localization should be within 1 m so that the route that a pedestrian takes can be recognized, (2) the beacon should send information that allows several pedestrians to be tracked at once, (3) the system should acquire data without putting pedestrians under psychological stress, and (4) the system should be affordable for retail stores. The aforementioned methods do not satisfy these needs.

The purpose of this study, therefore, is to develop an indoor localization system that meets the above requirements. We propose a linear localization method based on a trigonometrical survey, which uses an IR beacon. It is expected that the proposed technique will offer highly accurate localization due to the strong, straight beams of light used. It is also a low-cost option because the angle is measured directly. In this paper, we evaluate the usefulness of the suggested method by discussing two experiments that were undertaken using a prototype of the system.

II. ANGLE DETECTION OF IR BEACON ON PHOTODIODE ARRAY RECEIVER

A. Overview

Fig. 1 gives an overview of the proposed system, which consists of an IR beacon, a receiver, and a processing unit. The IR beacon transmits an ID signal using Pulse Position

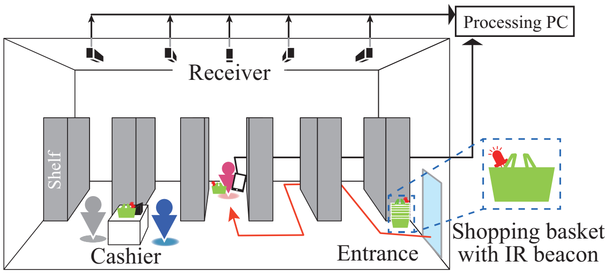

Fig. 1. Overview of proposed system

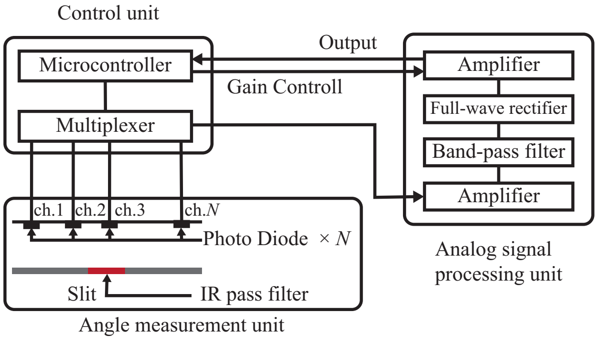

Fig. 2. Configuration of the receiver

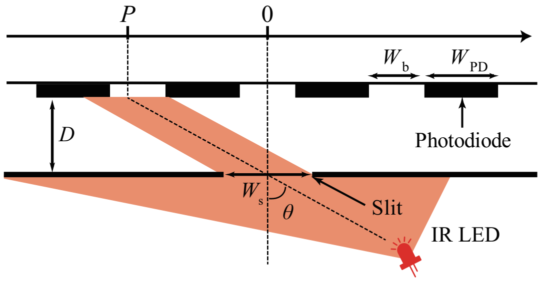

Fig. 3. Configuration of angle measurement

Modulation method of infrared rays and is attached to the object to be tracked[12]. The IR beacon is attached to a shopping bag to overcome the mental effects that may occur if one was attached directly to the consumer. A receiver installed in the ceiling measures the angle of incidence of the beacon ray, which can be used to calculate the position of the beacon and identify ID signals. The ID information and the position data are sent to a PC for processing via wireless communication.

Generally, at retail stores, the indoor traffic flow of pedestrians can be expressed using a combination of straight lines, as shown in Fig. 1, because the area is divided into parallel rows of product shelves. Thus, it is possible to track pedestrians by the combination of the receivers which can measure linear positon. This solution provides low-cost, highly accurate localization.

B. Receiver

The receiver is comprised of an angle measurement unit, an analog signal processing unit, and a controller unit, as shown in Fig. 2.

The analog signal processing unit consists of an amplification circuit, a Band Pass Filter (BPF) circuit, and a full-wave rectification circuit. The amplification circuit at the start is a trans-impedance amplifier, which converts a feeble electric current received on a Photo Diode (PD) into a voltage. The signal converted into the voltage is modulated on frequency f. The noise made by the background light is canceled by the BPF circuit. The signal passed BPF is decoded by a full-wave rectification circuit return. Finally, it is amplified again by adjusting the gain to a suitable voltage for A/D conversion.

The controller unit consists of a microcomputer and multiplexer, It selects the signals emitted by the arrayed PDs and adjusts the gain of the amplification circuit. In the analog signal processing unit, in order to reduce the estimation error caused by the dispersion of the elements in the circuit, all the PDs use a common circuit. By changing the input, the signal can be read – each of the PDs is chosen one by one.

The angle measurement unit detects the angle of incidence via a pinhole camera, a slit, and the arrayed PDs. The slit is made up of IR pass filters, which reduce the influence of light (other than that from the IR rays). To detect the angle of incidence, a slit is installed in the front of a PD array, parallel to the array's side, as in Fig. 3. Taking into account the incident radiation that passes the slit, the arrival position on the side of the PD array changes according to the angle of incidence. Because the slit is parallel to the array's side in Fig. 3, the width of the arrival light is the slit width W_{s}. The ray can be received in two PDs if W_{s} is large. Deflection is produced in the output between two PDs, depending on the arrival position of the light. We can calculate the central coordinate P of the arrival light by using this deflection. However, a situation where the outputs are not comparable might occur due to the width of the arrival ray — for example, if W_{s} is small and only one PD receives it, as in Fig. 4(a), or if W_{s} is too big and two PDs are saturated, as in Fig. 4(b). To prevent this scenario, we created a specific relationship between W_{b}, the slit width W_{s}, and the PD element width W_{PD}:

$$W_{\mathrm{s}} = W_{\mathrm{PD}} + 2W_{\mathrm{b}} \ , \tag{1}$$

as shown in Fig. 4(c). In the state that W_{s} is in a value of expression (1), We show the differs of the light receiving area of PDs depending on the position of the arrival ray in Fig. 5. This assumes that A_1 and A_2 are the output electric currents of PD#1 and #2, with the central coordinate of a pair of PDs as the origin. Fig. 5(a) shows a case where the central coordinate of the arrival ray is equal to that of the origin. In this case, the ray receiving the width on each PD would be (W_{s} -W_{b})/2. As the output electric current of the PD is proportional to the light requirement, the electric current ratio of the output can be expressed via the size of the ray-receiving area (in other words, the size of the ray receiving the PD width). Thus, this balance state [Fig. 5(a)] results in $A_1 = A_2$. If the arrival ray changed to Δx, the ray-receiving width on each PD would be (W_{s}-W_{b})/2 $\pm\Delta x$, as shown in Fig. 6(b). Thus, the ratio between the electric current outputs A_1 and A_2 would be:

$$A_1 : A_2 = \frac{1}{2}(W_{\mathrm{s}} - W_{\mathrm{b}}) - \Delta x : \frac{1}{2}(W_{\mathrm{s}} - W_{\mathrm{b}}) + \Delta x \ , \tag{2}$$

arranged as the following expression:

$$\Delta x = \frac{A_2 - A_1}{2(A_1 + A_2)}(W_{\mathrm{s}} - W_{\mathrm{b}}) \ , \tag{3}$$

where P is calculated in relation to the coordinates of each PD. From the positional relationship shown in Fig. 4, the incident

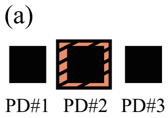

Fig. 4. Differences in light reception caused by slits' width (a) =too narrow, (b) = too wide, and (c) = appropriate

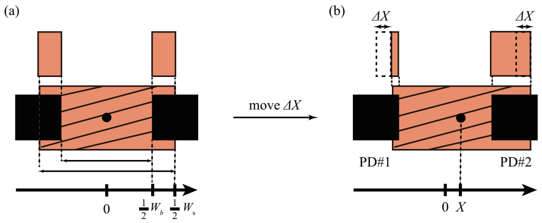

Fig. 5. Change of light income caused by changes to light position (a) equilibrium (b) not equilibrium

angle θ would be calculated as

$$\theta = \tan^{-1}\frac{P}{D}\ . \tag{4}$$

In addition, it becomes possible to regulate the measurable range of θ by regulating D. Using a given θ and the height distance between the height of the IR beacon and the attached receiver, the beacon position can be calculated

III. EVALUATION OF PROPOSED SYSTEM

A. Overview of prototype

An overview of the prototype of the receiver and the IR beacon is shown in Figs 6(a) and (b), respectively. The specifications for the system are given in Table I.

For the IR beacon, the OSI5XNE3E1E OptoSupply (Half Power Beam Width [HPBW] 140 deg.) and the PIC12F683 were assigned as the IR LED and the controller, respectively. The data signal can transmit 4 bits of data, which can identify 16 beacons as PD arrays. 12 PDs were utilized in this prototype. The frequency of tracking would be 0.6 s, due to the time taken to read all of the PDs.

For the receiver, we defined 75 deg. as the recognizable range because of the HPBW of the LED. The VBPW34FAS VISAY (HPBW: 130 deg.) was used as the PD element. To satisfy the recognizable range of 75 deg, a pair of PD arrays was utilized, as shown in Fig. 6(a).

TABLE I
PARAMETER OF THE SYSTEM

Detection range	±10-75 deg
Modulation frequency	5 kHz
Transmitting bit number	4 bit
Signal length T_{sig}(Max)	21 ms
Reading time per PD	50 ms
A number of PDs	12
Acquisition interval of Positional data	0.6 ms

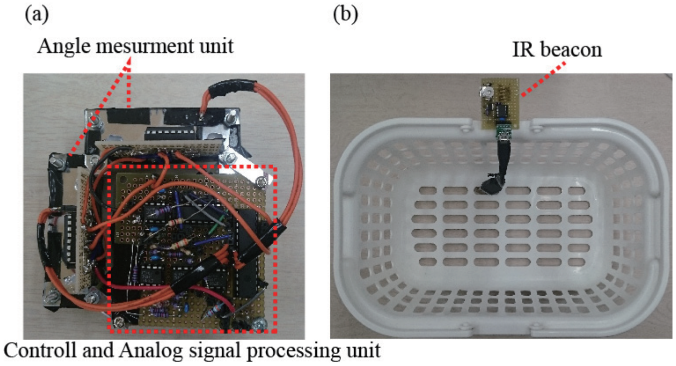

Fig. 6. External views of (a) the receiver (b) the IR marker

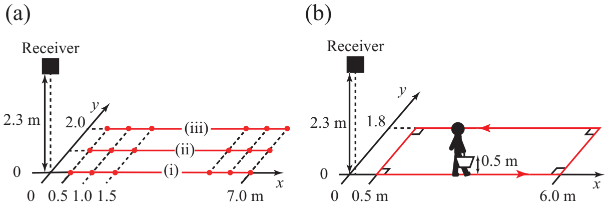

Fig. 7. Experimental environments: (a) for measuring errors in static beacons; (b) for calculating ID recognition rates and verifying positioning under dynamic beacons

B. Static localization experiment

An evaluation of the localization was conducted by using the prototype in the passageway in the laboratory. The experimental conditions are shown in Fig. 7(a). We measured the position when one IR beacon was placed on every 0.5 m in along the passageway from 0.5–7.0 m (as shown in red point in Fig. 7(a)). The localization results are shown in Figs 8(i), (ii), and (iii), which give the estimated results and the estimation error for each condition (y = 0 m, 1 m, and 2 m). Looking at the estimation errors, 8(i), (ii), and (iii) all demonstrate similar

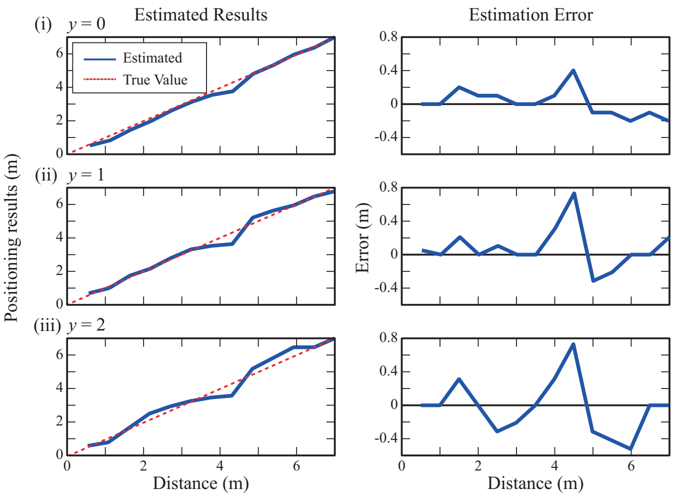

Fig. 8. The relationship of between the distance and positioning error

TABLE II
THE RESULT OF ID IDENTIFICATION

	Correct	Error	Recognition rate
Total	222	54	80%
Without data lacks	222	24	90%

tendencies. It is evident that the error tends to be large when y ingredient is bigger. When focusing on the area around x = 4.5, it can be seen that each of the estimated results contain similar levels of error. This can be considered an adjustment issue on the gain controller, which has caused the saturation of the receiving signal, thus creating an inaccurate estimate of light income.

All in all, the results were reasonably precise (maximum error: 0.7 m), even if the possibility of a large local error occurring existed. This suggests that highly precise pinpointing of areas in the passageway is possible.

C. Dynamic localization experiment and ID recognition

We also conducted a localization experiment using a moving IR beacon. Here, we examined the usefulness of the proposed method, analyzing the data in chronological order. In addition, we inspected ID identification precision at the same time. The experimental conditions are shown in Fig. 7(b). In order to evaluate the dynamic situation of a pedestrian, we asked the pedestrian to walk 12 laps of a rectangular course of 5.5 m × 1.8 m, carrying a bag to which the IR beacon, which transmits the ID number, was attached.

The results of the tracking and ID recognition, which were got every 0.6s, are shown in Fig. 9 and Table II, respectively. The blue circle, the red square, and the green square denote the points where the ID was definitely detected, the points where the IR ray only was detected, and the points where neither the IR ray, nor the ID could be detected, respectively. From these results, the estimated movement course is along to the traffic flow of pedestrian in this experiment. Periodically, the IR ray could not be recognized by the receiver. This is because of the shielding effect caused by the body of pedestrian. This suggests that the relative positions of the marker and the receiver are important. The number of moments of identification was 276 over the 12 laps. Of these, 222 supplied a correct ID and 54 were incorrect. Thus, the recognition rate was 80%. Additionally, it can be said that the recognition rate was 90% when the 30 instances where the light could not be received were excluded. There is room for improvement here, therefore, by making adjustments to the decoding program in the receiver so that the light is detected with more accuracy.

The experiment indicated that the tracking precision and ID precision were at high enough levels for the proposed method to be considered valid. The results suggest that the proposed method could be applied to the tracking of the traffic flow of pedestrians.

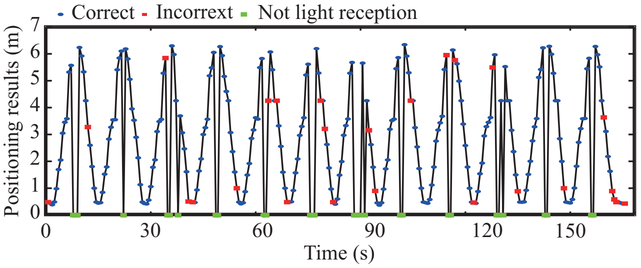

Fig. 9. Positioning data in the experiment

IV. CONCLUSION

The purpose of this study was to develop an indoor positioning method for retail stores that would enable to capture regarding the traffic flow of pedestrians. We propose an IR beacon linear localization method based on a trigonometrical survey. To evaluate the performance of the proposed method, we undertook experiments of IR beacon tracking and ID recognition. Through the experiments, it was confirmed that the estimation accuracy was within the error of less than 0.7 m for static positioning and dynamic positioning estimation was along the movement of the IR beacon. Moreover, the ID recognition rate was about 90% when the IR ray was received. Therefore, the usefulness of the proposed method for tracking the traffic flow of pedestrians indoors was confirmed.

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