Physics

Weights & Measures fields

Okayama University *Year* 2004

A new laser-based position sensor with the ability of detecting the incident angle of a light

Mitsuru Baba* Norimasa Michiue†
Daisuke Narita‡ Kozo Ohtani**

*Okayama University
†Okayama University
‡Okayama University
**Hiroshima Institute of Technology

IMTC 2004 – Instrumentation and Measurement
Technology Conference
Como, Italy, 18-20 May 2004

A New Laser-Based Position Sensor With the Ability of Detecting the Incident Angle of a Light

Mitsuru Baba[1], Norimasa Michiue [1], Daisuke Narita[1], Kozo Ohtani[2]
[1]Okayama University,1-1,NAKA 3-chome,Tsushima,Okayama,700-0811,Japan
[2]Hiroshima Institute of Technology, 2-1-1, Miyake, Saeki-ku, Hiroshima, 731-5143, Japan
Phone: +81-86-251-8186, Fax: +81-86-251-8256, Email: baba@sdc.it.okayama-u.ac.jp

Abstract *– This paper describes a new sensor with the ability of simultaneously detecting the position and the incident angle of a light. The basic principle is to detect the difference in the peak positions between two image sensors. We have designed and build three kinds of prototypes of the proposed sensor. We experimentally verified the practicable accuracy of the proposed position sensors.*

Keywords *– Position Sensor, Laser, Incident angle, Rangefinder*

I. INTRODUCTION

To acquire spatial information, most laser-based position measurement systems, such as rangefinders and the motion capture system, are utilized so as to receive the reflected light after light has been projected onto an object, or to directly receivethe light from a light source attached to the object. A laser is often used for such a system because it has the advantage of high intensity, high directivity, and monochromaticity [1]. In measuring systems, the high directivity of the laser is useful from two points of view: the transmission of the energy of the light and the maintenance of the optical path. The transmission of the energy of the light is often used for the measurement. In comparison, the maintenance of the optical path has seen less use. Since information on the optical path includes information on the position or orientation of objects, utilization of the information on the optical path in measurements has great potential for development in laser-based measurement systems.

In order to acquire information on the optical path, it is necessary to use a sensor that is able to detect both the position and the incident angle of the light. A sensor exclusively for detecting the position of a light spot and a sensor exclusively for detecting the incident angle have already been developed. The sensor typically used for the former is a CCD (charge coupled device) [2] or a PSD (position sensitive device) [3]. An example of the latter has been marketed by the Hamamatsu Photonics Co [4]. However, a sensor which can simultaneously detect the position and the angle of a light spot has not yet been developed, and up to now, conventional sensors such as the CCD or PSD have been used. Ordinary laser-based position measurement techniques using a CCD or PSD have, as a result, employed algorithms exclusively using the light spot's pixel position.

If an image sensor can detect both the incident angle of a light and its position, this image sensor could be effectively applied to a number of situations. Thus, we have previously proposed a one-dimensional sensor type [5], which can measure a one-dimensional position and one-dimensional incident angle onto the sensor at a given position of a y-direction.

In this paper, we describe the development of the extended version of the previous sensor, consisting of a two dimensional type sensor which can measure a two-dimensional position and two-dimensional incident angle.

We have designed and built a prototype of this two-dimensional sensor system in which the proposed principle is implemented. We first examined its accuracy by measuring the position and the incident angle of the prototype sensor system. Next, we tested the usefulness of the sensor by applying it to a two-dimensional position measurement.

II. PRINCIPLE OF MECHANISM TO DETECT THE LIGHT'S POSITION AND ANGLE

As a first step for determining the basic concept of the sensor system under consideration, we studied the intensity distribution of a light spot which was obliquely projected to the image sensor plane.

By a preliminary test, we arrived at the idea of detecting the position and the incident angle by using the outputs of sensors located at different positions in the deep direction instead of using the intensity distribution of one sensor[5].

Fig. 1 shows the basic construction of the proposed sensor system and the intensity distributions of the light onto the sensor when the light is projected at an angle with respect to the sensor plane. The sensor system consists of two linear-type sensors (a front sensor and a rear sensor), which are arranged at a short distance from each other in the z-direction, and are arranged in the x-direction. The light is projected at a given angle to the x-direction from the z-direction. The vertical axis of the figure is the intensity received by each sensor. Black circles show the measured values, and the solid

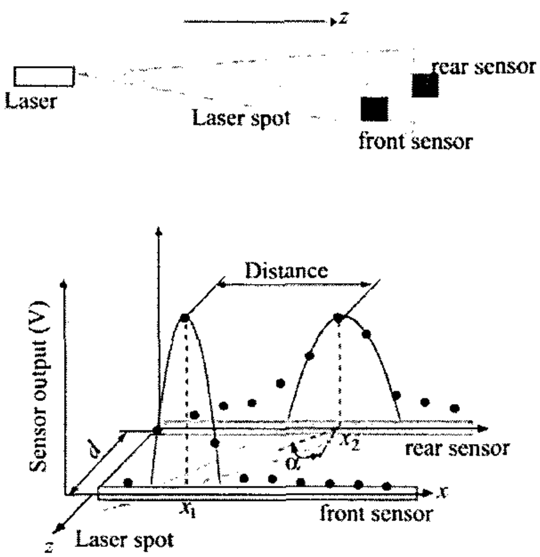


Fig. 1 Basic construction of the proposed sensor and the intensity distributions of the light onto the sensor

lines are approximated by a curve of the second-order polynomial, which uses the peak value and the two values of the adjacent pixel of the sensor.

According to the results of the above preliminary experiments, we therefore estimated the positions and the incident angles of lights that were obliquely projected to the proposed sensor as follows: we regarded the peak position, x_1, of the intensity distribution in the rear sensor as the actual position of a light, x, that is to say, as it is expressed by equation(1);

$$x = x_1 \qquad (1)$$

When the distance between the front sensor and the rear sensor is d, and x_1 and x_2 is the actual peak position of the front sensor and the rear sensor, respectively, then the incident angle α is calculated using equation (2).

$$\alpha = \tan^{-1} \frac{x_1 - x_2}{d} \qquad (2)$$

III. SENSOR COFIGURATION

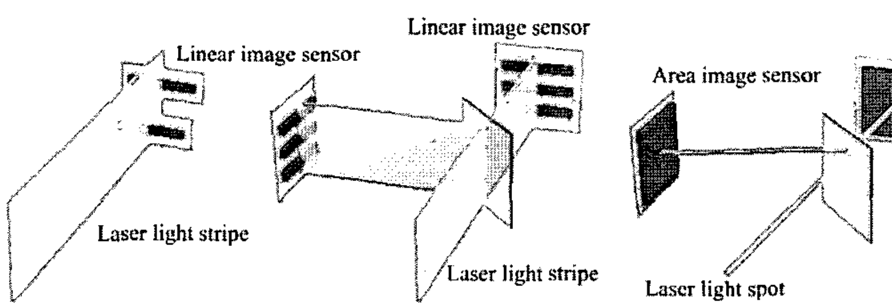
Fig. 2 shows the three types of configurations of the proposed sensor: type I, type II, and type III.

Type I measures the one-dimensional position and the one-dimensional angle, which consists of two linear array-type sensors whose depth positions are slightly different, as shown in Fig.2 (a)[5].

Type II measures the two-dimensional position and the one-dimensional angle (horizontal direction). The operating principle of type II is almost the same as that of type I. What sets type II apart is the use of a half-mirror and sensor plane. The sensor plane of type II consists of multiple linear sensors arrayed vertically, as shown in Fig. 2(b). The light input onto the sensor is divided into two directions by the half-mirror, and directed toward two sensor planes.

Type III measures the two-dimensional position and the two-dimensional angle (horizontal and vertical direction), as shown in Fig.2(c). The operating principle for the configuration of type III is the same as type II, exclusive of the sensor plane. The sensor plane of type III is constituted from an area image sensor.

The determining method of the angle for Type II and Type III is different from that of Type I. Fig. 3 displays the distribution of area sensor 1 and area sensor 2 around the same axis. If the light hits line AB of the figure vertically, then the peak positions of area sensor 1 and area sensor 2 are equal. However, when the light hits line AB obliquely, the



(a) Type I (a) Type II (a) Type III

Fig. 2 Sensor configuration

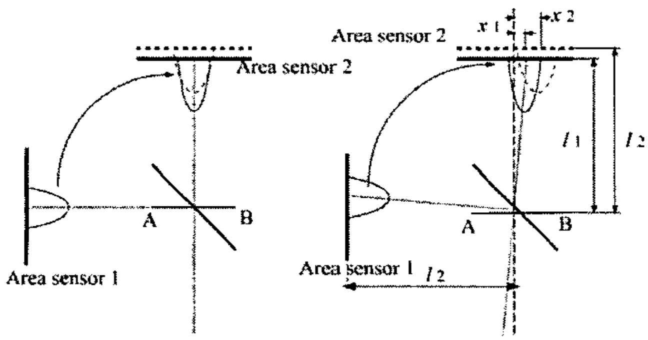


Fig. 3 Principloe of detecting the position and the incident angle of the light in the Type II and Type III

peak positions of area sensor 1 and area sensor 2 differ, and the deviation is proportional to the magnitude of the incident angle hitting line AB of the figure. The position and the incident angle, α, of the light is then calculated as follows:

$$\alpha = \tan^{-1} \frac{x_2 - x_1}{l_2 - l_1} \quad (3)$$

Types I, II and III can be used depending on which type of sensor is needed.

IV. PROTOTYPE SENSOR SYSTEM

A photograph of the prototype type II sensor system is presented in Fig. 4. The test configuration consisted of a laser source and the prototype sensor system. The sensor system consists of a half-mirror and sensor plane, which are composed of multiple linear CCD image sensors. The half-mirror is a cubic construction, with dimensions of 50mm x 50 mm x 50mm. The image plane of the image sensor consists of two planes oriented orthogonally to each other. The distances between the planes and the center of the half-mirror are 40mm and 45mm, respectively. Each image plane is equipped with three linear CCD image sensors containing 2048 pixels that are 14 μm in size. Thus, this image sensor can acquire three sets of data simultaneously.

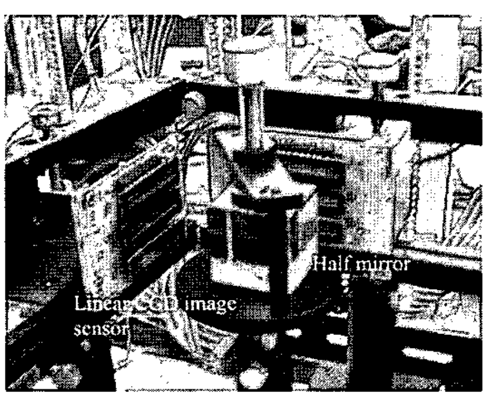


Fig. 4 Photograph of the experimental setup of the Type II

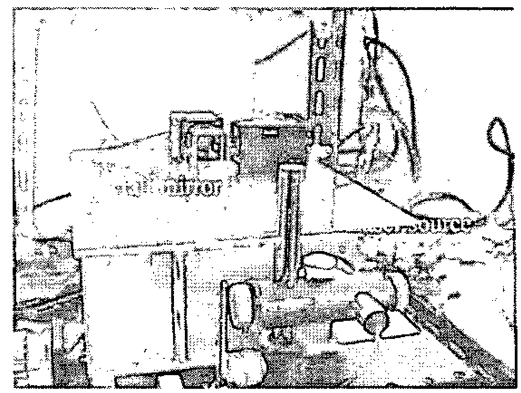


Fig. 5 Photograph of the experimental setup of the Type II

Fig.5 shows the photograph of the prototype III, which consists of a laser, half-mirror, and a couple of two-dimensional CCD cameras.

V. EXPERIMENT

We measured both the position and the angle of the sensor for a variety of incident angles in type I, II, and III.

Figs. 6(a), (b), and (c) show the examples of the output of the positions by type I, type II, and type III versus the actual positions when the light is projected obliquely. In Figs. 6(a) and (b), the horizontal axes are the actual peak positions, and the vertical axes are the output. Fig. 6(a) is type I, and the projected angle is 40 degrees. Fig. 6(b) is type II, and the projected angle is 5 degrees. Fig. 6(c) is the result of type III. In Fig. 6(c), the light is projected at a 3 deg, and the vertical axis shows the position of y-direction, the horizontal axis shows the position of x-direction. The maximum relative error of the measured data of type I was 1.81%, and that of type II was 0.89%. The errors of x-direction and y-direction of Type III are 3.5% and 2.7%, respectively.

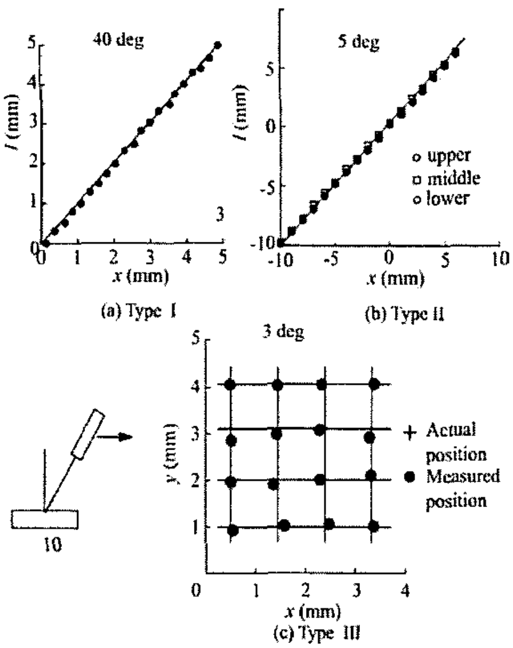


Fig. 6 Outputs of the positions by the Type I, Type II and Type III versus actual positions

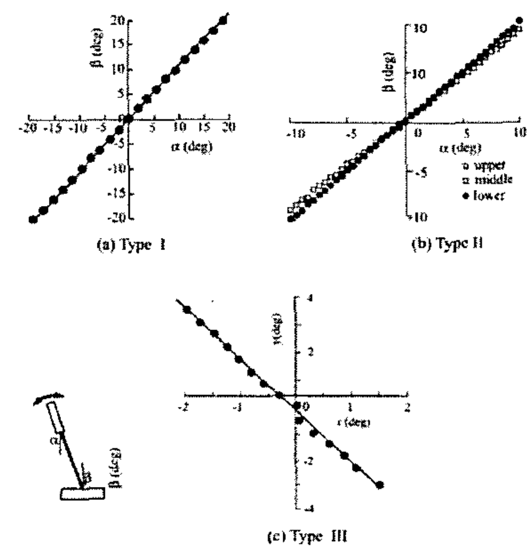


Fig. 7 Outputs of the angles by Type I, Type II, and Type III versus actual angles

Figs. 7(a), (b), and (c) show the output of the sensors when the incident angle of the light are projected obliquely. Fig. 7(a) shows the measurement results of the incident angle from -20 degrees to +20 degrees for type I. Fig. 7(b) shows the measurement results from -10 degrees to 10 degrees for type II. In these figures, α is the projected angle of the laser, and β
is the incident angle onto the sensor. The maximum error was 0.46 degrees in type I and 1.1 degrees in type II. Fig. 7(c) shows the result of type III. In Fig. 7(c), the vertical and horizontal axes are the measured angle of y-direction and x-direction, respectively. The maximum errors of x-direction and y-direction inType III are 1.3 degress and 1.4 degrees, respectively.

From these results, it is clear that the proposed position sensor has the ability to accurately measure both the position and incident angle.

VI. APPLICATION TO LASER-BASED MEASUREMENT SYSTEM

In order to confirm the usefulness of the present sensor system, we designed and built three-dimensional measurement systems in which the sensor was implemented. This system is intended to be used for object tracking or motion capture.

In ordinary systems, the position of a moving object is usually measured by using a single light source or a single

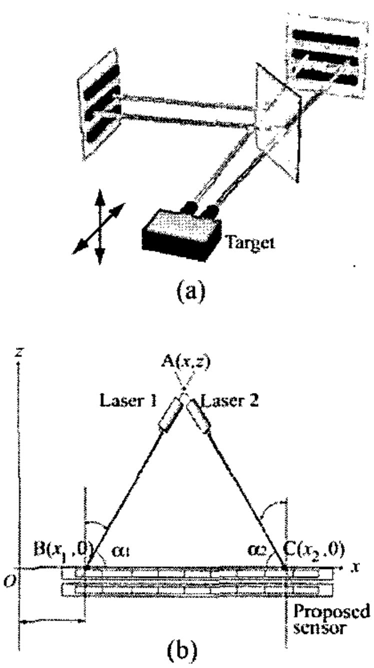


Fig. 8 Three-Dimension position measurement system with Type II

reflected marker attached to the object, and two image sensors with a known distance between them. However, the use of our sensor system permits a system configuration different from such conventional configurations.

Fig. 8(a) illustrates the 3-D measurement system used in the proposed sensor. As shown in the figure, two lasers are attached at a horizontally arbitrary angle with respect to a target When the received positions of the two light spots are $x1$ and $x2$, respectively, and the incident angles are α_1 and α_2, respectively, the position of the target, (x, z), is calculated as follows:

$$x = \frac{x_2 \tan\alpha_2 - x_1 \tan\alpha_1}{\tan\alpha_1 + \tan\alpha_2}$$
$$z = \frac{(x_1 - x_2)\tan\alpha_1 \tan\alpha_2}{\tan\alpha_1 + \tan\alpha_2} \quad (4)$$

Fig. 9 shows the measurement results. In this figure, white squares are actual positions, and black circles measured positions. The maximum error of the measured x-positions and the measured z-positions were about 2.5% and 4.3%, respectively. The parameters needed in this measurement are both the peak positions and the incident angles, which can be acquired exclusively using our sensor. This experiment demonstrates the ability of the sensor to detect incident angles. Unlike with ordinary systems, the present system did not require information on the distance between the two sensors, and also allowed for a simpler configuration.

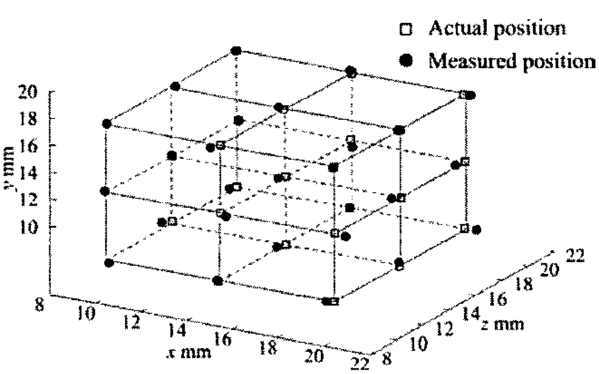


Fig. 9 Measurement results by type II

VII. CONCLUSIONS

We presented a new laser-based position sensor, which has the ability of simultaneously measuring the incident position and the angle of a light spot or a light stripe. The basic principle to measure the difference in peak positions of a light between two sensor. We designed and built three kinds of prototype sensors: Type I, Type II, and Type III. Experimental results demonstrate the practicable accuracy of the proposed position sensors

REFERECES

[1] Wlter Koechner: Solid-State Laser Engineering, Springer-Verlag :New York, 1999.

[2] Gopel W, Hesse J and Zemel J N: Sensors, Volume 6 Optical ensors, Weinheim:VCH, 1992

[3] Woltring H J, Single-and dual-axis lateral photodetctors of rectangular shape, IEEE Trans. Electron Devices, ED-22, pp581-6, 1975

[4] Hamamatsu Phonics 2002 Products Catalog

[5] M Baba and K Ohtani, "A New Sensor System for Simultaneously Detecting the Position and Incident Angle of a Light Spot", Journal of Optics, A: Pure and Applied Optics, Vol.4, No.6, s391-s399, 2002