Automation and Robotics in Construction XI
D.A. Chamberlain (Editor)

A three-dimensional positioning system using laser beams and its application to the undulation measurement of a golf course green

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Abstract

We have developed a 3D positioning system and have applied it to undulation measurement on the green during the construction of a golf course. This positioning system can quickly and precisely position and control mobile objects. It is particularly suitable for positioning construction robots over a wide area. This paper describes the fundamental structure of the 3D positioning system, the procedure for positioning using the undulation measurement system, and the results of experimental work.

1. INTRODUCTION

Controlling mobile robots for outdoor use requires that a positioning system be used in a wide-open field.

Various studies have been conducted on positioning systems using a GPS, an automatic tracking total station, and similar devices. However, although they offer some advantages, these devices are not versatile or fast.

The system presented in this paper employs two laser beacons that emit rotating laser beams. This system is an improved version expanding the previous one, which was presented in the Fifth ISRC, from two dimensions to three dimensions. Another improvement is that its photosensor is capable of detecting a laser beam from any direction.

A short measurement time as well as good measurement precision is critical for controlling the position of a mobile robot. The present system has a measurement cycle of 0.1 seconds, which is short enough to control running robots.

In its application to undulation measurement on the green, the photosensors also move along with the measurement vehicles to provide reliable 3D position data.

2. 3D POSITIONING SYSTEM

The 3D positioning system in this study consisted of two laser beacons set at two reference positions and a photosensor fixed to the mobile object to be positioned. Each of the laser beacons emitted two laser beams that rotated horizontally.

The photosensor was vertically long and could detect these laser beams.

As shown in Figure 1, the positioning system used these laser beams to give the two apex angles of a horizontal triangle with its apexes placed at the two beacons and sensor. Using these angles and the known distance between the beacons, the system carried out a trigonometric calculation to determine the plane coordinates (x, y). It also determined the vertical coordinate (z) from the position of an incident beam on the photosensor. These coordinates gave the 3D coordinates (x, y, z).

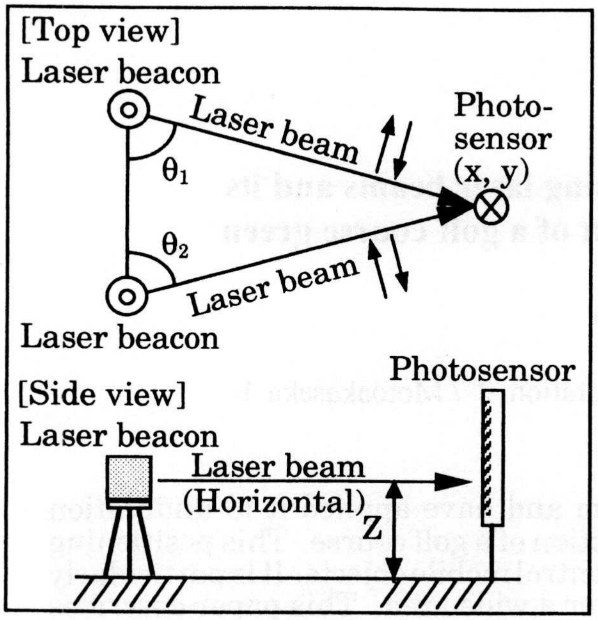


Figure 1. Principle of measurement

2.1. Principle of measuring the apex angles of a horizontal triangle

This principle is as follows:

(1) A laser beacon emits two laser beams that rotate at a constant speed around the beacon in opposite directions.

(2) The two beams periodically overlap in one fixed direction, which is called the reference direction.

(3) The beams come into any other direction separately with an interval of time that depends on the reference direction angle, as seen in Figure 2.

(4) The photosensor first receives the clockwise beam and then the counterclockwise beam over a certain time interval, t_1. It also receives the counterclockwise beam and then the clockwise beam over a certain time interval, t_2. As Figure 3 shows, the angle from the reference direction, θ, is given by

$$\theta = t_1 / (t_1 + t_2) \times 180° \qquad (1)$$

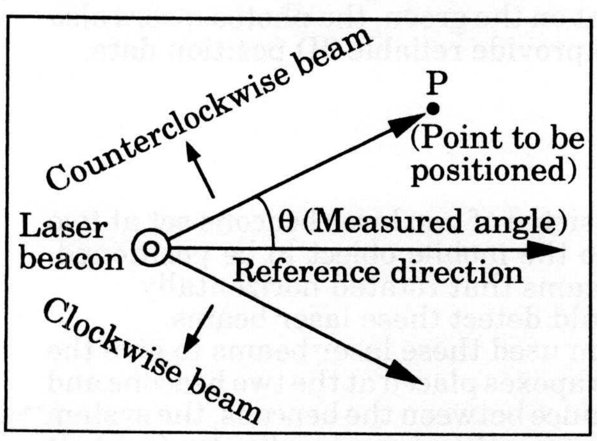


Figure 2. Principle of angle measurement

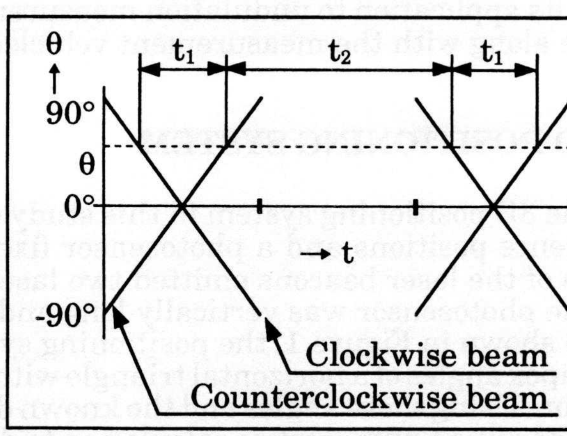


Figure 3. Time chart for angle measurement

2.2. Rotating laser beams

The above principle holds true only when the clockwise and counterclockwise beams from a beacon are exactly symmetrical with respect to the reference direction.

The present system employed a rotary holder and prisms to emit two symmetrical laser beams in opposite directions with high precision (Ref. 1).

2.3. Omini-directional photosensor

The photosensor employed in the present system must determine from which laser beacon it receives the laser beam.

A conventional method employs a laser shield to restrict the angle of each incident beam in order to separate the laser beams emitted by one beacon from those emitted by another.

The present method had two laser beacons that rotated at different rates. The photosensor used a software technique to distinguish the time period for receiving beams emitted by one beacon from that for receiving beams emitted by the other beacon, and hence to differentiate between the two beacons. Figure 4 shows these two distinguishing methods.

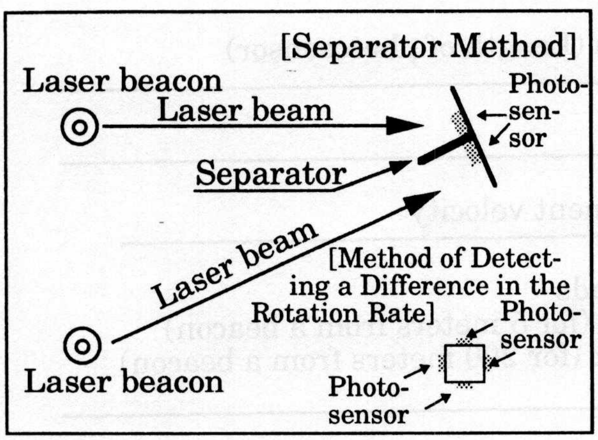


Figure 4. Methods of distinguishing two laser beacons

The present system had a 10% difference in the rotating rates of the two beacons. The beams from one beacon rotated at 600 rpm, while those from the other rotated at 540 rpm. This method has the following features:

(1) The photosensor is capable of receiving laser beams in all directions of 360°, whether the moving object is rotating or stationary;

(2) The photosensor is compact, and hence measurement errors due to the existence of a non-zero area in the light-receiving portion are small; and

(3) The present system requires only one electric circuit for measuring the time intervals for receiving laser beams, compared with the conventional technique, which requires two circuits.

2.4. Permissible range of velocities of a moving object

The present system is basically a device for measuring angles. The velocity of a mobile object with a photosensor is defined by a change in the angular velocity component of the laser beam.

The design speed set in the present system is the normal speed of human walking (3.6 km/hour) at a distance of five meters from a laser beacon. If the photosensor is placed 200 meters (i. e., the maximum permissible distance in this system) from the beacons, the permissible velocity of a mobile object may simply be 40 times 3.6 km/hour, or 144 km/hour.

Table 1
Specifications of the 3D Positioning System

	Measurement of horizontal angels
Measurement accuracy	±0.025 deg (±50 mm/100 m)
Repeat accuracy	±0.001 deg (rms)
Range of measurable angles	60°
	Measurement of height
Horizontal accuracy	±0.003 deg (±5 mm/100 m)
Resolution	5 mm
Measurement range	1,760 mm (Length of photosensor)
Measurement distance	200 m
	Measurement velocity
Measurement cycle	0.11 seconds
Permissible velocity of a mobile object	3.6 km/hr (for 5 meters from a beacon) 144 km/hr (for 200 meters from a beacon)

3. APPLICATION OF THE POSITIONING SYSTEM TO UNDULATION MEASUREMENT ON THE GREEN

The positioning system applied to undulation measurement on the green had a photosensor measuring 1760 mm in height and a data processing computer built in a four-wheel measurement vehicle.

While on the move, this system took a measurement of 3D position data every second. The obtained data was then stored in the computer. The system took about 2000 measurements on one green to find very small ups and downs.

These measurements were then analyzed by the computer to produce a contour map, a bird's-eye view, and a graphical representation of the scenery.

Thus, this type of precise measurement was able to provide an as-built drawing showing slopes for precise water control, while providing other useful services to golfers. No other measurement system has produced such a wide range of precise information.

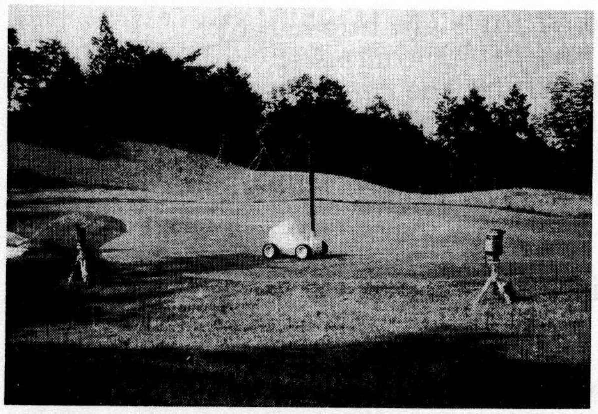


Photo 1. Measurement vehicle and two laser beacons

3.1. Structure of the undulation measurement system

The undulation measurement system consisted of two laser beacons, a measurement vehicle with a photosensor and a data processing computer, and a graphic plotter.

Table 2
Specifications of the four-wheel measurement vehicle

Item	Specifications
Dimensions of the main body	740 mm (H) x 850 mm (W) x 1000 mm (L) (excluding the handle and photosensor)
Weight	70 kg
Photosensor	1760 mm in length, omni-directional
Computer	NEC98 Notebook
Wheels	Four low-pressure, rubber tires
Body	FRP
Steering	Rear-wheel steering
Brake	Drum brake on front wheels

3.2. Measurement procedure

The measurement procedure was as follows:
(1) To place laser beacons outside the green;
(2) To manually move the vehicle along the periphery of the green to measure and store data on the peripheral shape; and
(3) To move the vehicle thoroughly on the green to receive laser beams every second and store contour data.

3.3. Graphical plotting

A graphical plotter was connected to the computer to create the following graphics:
(1)Contour map: The plotter drew the peripheral shape and contour map of the green with a contour line interval of 1 cm or more;
(2)Bird's-eye view: The plotter could draw a bird's-eye view at any vertical

magnification, in any bird's-eye position, and at any sight-line height;

(3)Graphical representation of the green: A graphic computer could produce a smooth, realistic, photographic bird's-eye view from the contour data points and output it to a color printer or video cassette recorder; and

(4)Others: The computer could display the calculated area and calculated differences of elevation.

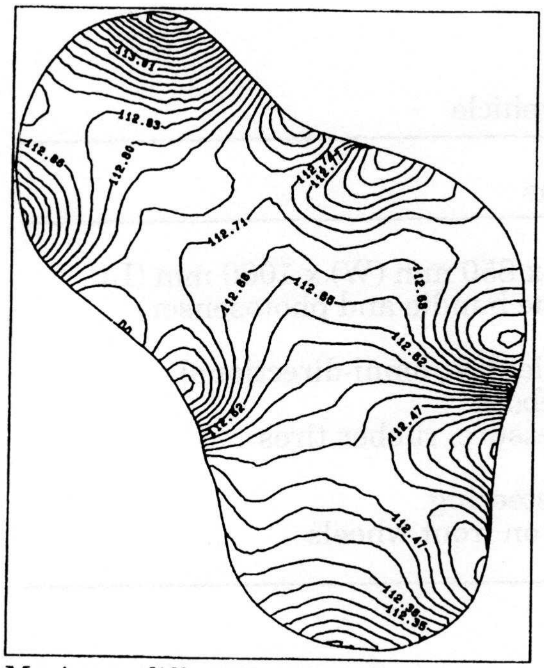
3.4. Measurement results

Figure 5 shows the measured contours. Figure 6 shows the measured bird's-eye view.

There were no abnormalities in any of the 2000 measurement points. We encountered no difficulties in taking measurements on either rainy days or sunny days.

At present, the undulation measurement system is being applied to a golf course that is being developed by our corporation, as well as other existing golf courses.

This system can survey four holes per day, work which includes carrying all the whole equipment and planning the measurements.



Maximum difference in height of the green: 1.125 m
Area of the green: 886.094 m^2

Figure 5. Contour map

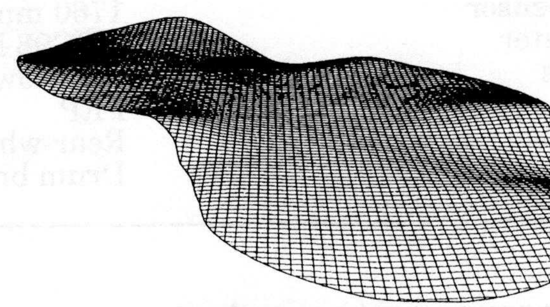


Figure 6. Bird's-eye view

4. CONCLUSION

We applied the 3D positioning system using laser beacons and a photosensor to survey a golf course. Using a moving vehicle to carry the sensor, we were successful in producing reliable data on the contours of the green.

This system could carry out omni-directional positioning. It can now also be applied to the positioning and controlling of construction robots.

In the future, we will study the possibility of applying our positioning system to automatic control, the positioning of high-speed objects, and determining azimuth of a mobile object using two photosensors.

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