A POSITIONING SYSTEM FOR MOBILE ROBOTS IN CONSTRUCTION APPLICATIONS ("LASER POSITIONER")

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ABSTRACT

The Laser Positioner is a unique system that determines the position of a mobile robot in a wide-open field.

The measurement system employs a new technique in which particular laser beacons are used to emit two symmetrical laser beams that travel in opposite directions around the beacon and a sensor then detects the beams to measure the arrival time ratio between the beams. The two beacons are set at reference positions to enable beam-detection by the sensor mounted on the robot to immediately determine the exact two dimensional location of the robot (according to x- and y-coordinates) wherever robot moves.

Tests using a prototype system revealed a measurement error of 4 mm or less in a 26 m x 16 m square area. Consequently, the measurement occur of this system is adequate for construction surveying applications.

This paper describes the principles of detection, test results, and system applications.

1. Introduction

Because most types of construction work require positioning control, a technique by which positions can be automatically determined is essential for robotics applications in construction work. Conversely, few robotics systems have been developed for special-purposes' outdoor applications.

Our company has developed a self-navigation system that uses a gyrocompass to control the moving robot with emphasis on the technology used to develop mobile robots for construction applications. Accordingly, we developed the Laser Positioner as a system that offers very precise positioning control over a wider range. Testing of a prototype positioning system has indicated a higher precision than expected, especially for construction surveying applications. Such a system will undoubtedly facilitate the development of more robots for construction applications.

Surveying has previously involved the use of transits, levels, and tape measures. The recent development of electronic distance meters has improved surveying work, but manual collimation is still required. As a result, such devices for automated surveying are not suitable. This has retarded to the development of robots for automated construction work.

The features of the Laser Positioner are as follows:

1) Capable of noncontact surveying over a wide area. This makes the Laser Positioner ideally suited for construction work. (The measurement range of a system is 300 m.)
2) Highly precise measurements (0.015% of base length).
3) Automatic high-speed positioning of moving objects. (The time for a measurement run is 0.1 s.)
4) Compact lightweight, and durable sensor without moving parts (only transistor elements).
5) Capable of direct input to a computer to facilitate data processing.
6) Simple operation.
7) Low cost.
8) Capable of multiple and simultaneous measurements using multiple sensors.

2. Principles of Measurement

The laser beacon uses a laser oscillator, prisms, a mirror, and a rotary motor to emit two laser beams that rotate around the beacon in opposite directions. The sensor includes a photosensor that receives the laser beams, an electronic circuit for time measurements, and a computing device to indicate the location of the sensor.

In an actual configuration, the two beacons are set at reference positions, and the sensor is placed at an object point. The time interval between the detection of two successive beams by the sensor is determined using an electronic timer. This interval is proportional to the angle between the ariving beam and reference line (the line at which the two beams arrive simultaneously). Therefore, the two angles evaluated by using the two beacons, and the known distance value between the beacons are used to determine the exact location of the sensor (according to the x- and y-coordinates on a plane). Photo 1 and Fig. 1 show the configuration the position-determining system.

The configuration of the two symmetrical beams, the evaluation of angles, and determining the sensor location are explained as follows.

2-1 Symmetrical beams

The laser beacon divides one laser beam into two identical, symmetrical beams by using prisms, a mirror, and a rotary holder.

As shown in Fig. 2, the laser beam emitted up passes through a hole, is deflected at a right angle by a prism, and is divided into two beams by the beam splitter mounted on the holder. One beam (A) travels straight while the other (B) is deflected at a right angle. Beam (A) rotates according to the holder rotation. Beam (B) is in deflected at a right angle by another prism to reach the axis of rotation, where it again deflected at right angles by a stationary mirror to ensure that the two split beams always travel in parallel planes.

Because the stationary mirror is fixed, Beam (B) rotates in the opposite direction of the holder and Beam (A). When looking perpendicular to the parallel beam planes, the two beams always appear symmetric in regard to the normal line of the mirror. Because reflection on the rear surface of the mirror is not possible, the previously described symmetry only holds true in the first and fourth quadrants.

Note that because the axis corresponds to the normal line of the stationary mirror, its direction depends solely on that of the beacon.

2-2 Evaluating angles

When the rotating holder is placed on a horizontal plane and is rotated at a constant speed, the two symmetric beams rotate in opposite directions - clockwise (CW) and counterclockwise (CCW).

At a measurement position, the sensor is long enough (vertically) to detect both beams separated at different levels. In the following expressions, t_1 indicates the time interval between CW beam detection and the next CCW beam, and t_2 indicates the time interval between CCW beam detection and the next CW beam. Angle θ (between the symmetry axis and the line passing through the measurement position and stationary mirror) are obtained by:

$$\theta = \frac{t_1}{t_1 + t_2} \times \pi \qquad \text{in the first quadrant}$$

$$\theta = - \frac{t_2}{t_1 + t_2} \times \pi \qquad \text{in the fourth quadrant}$$

Figure 3 shows the relationship between the angle and time interval.

2-3 Determining the sensor location

Two laser beacons are used to locate a position on a flat plane. The beacons are placed at predetermined reference positions with their axes in exact coincidence. Two sensors are attached to opposite sides of a board placed on an object point so that one sensor can only receive the laser beam from one beacon. In this way, combining a beacon and a sensor enables one of the two angles to be determined; the other combination determines the other angle.

A timing device and a microcomputer are installed on the object so that the time intervals from the sensors being measured by the device can be easily transferred to the microcomputer. In this way, by using the known distance value between the two reference positions input into the microcomputer, two-dimensional coordinate data can be obtained on the object on a realtime basis.

3. Testing Procedure and Results

A He-Ne laser was used for measurements made during the testing. Figure 4 shows the optical path within a beacon. To minimize the effect of axis vibration by the motor, an even number of reflections by one prism or mirror should be selected, to in current design. The stationary mirror included twin plane mirrors arranged orthogonally so that the reflected laser beam would not interface with the prism.

The rotary holder was driven directly by a hollow shafted motor at a rotation speed of 600 rpm. Data was output every tenth of a seconds.

The 20 cm-long sensor included an electronic circuit for the same input value determined for where the laser beam was detected along the length. The timing was set using 10 MHz quartz crystal oscillator. The rotation cycle of the laser beam was set to 0.1 s to provide an angle resolution of $2\pi \times 10^{-6}$rad.

Test runs were made on lattice points drawn on a 26 m x 16 m floor.

Figure 5 shows the test results. The maximum measurement error was 4 mm. In the figure, the error scale is magnified 100 times the distance scale (i.e., a 2m distance corresponds to a 20 mm error).

Ten measurements were made at each point, and the average value is shown in the figure. The scattering of these measurements was about 1 mm.

Due to the structural limitations of the equipment, the range of the angle was from 0 to 70 degrees.

4. Robot Applications for Construction Work

Our company has already developed a system that uses the Laser Positioner to determine the position of a workship. Other system applications are being planned for future development.

4-1 System for determining workship positions

Determining a position at sea is difficult because marking is impossible. Because simultaneous confirmation of position is required for pile driver operation and similar work, manual collimation is done using a transit on a stationary platform. At the same time, ocean waves cause the object to move, which inhibits precise determination. For this reason, automation is urgently needed for such applications.

Satisfactory results were obtained by using a system developed to determine the position of a pile driver ship. The system includes two laser beacons, two sensors, and a host computer. The computer outputs a graphics display of the position and attitude. When compared to the electronic distance meters equipped system being currently used for large ships, this system features: 1) small size for small ships; 2) ability to follow the movement of a workship for surveying from close distances; 3) use at night; and 4) simultaneous use for positional control of multiple ships.

4-2 Proposed applications for the automatic driving of heavy machines

1) Press rollers

Because press rolling is controlled according to the number of rolls, positional control is needed to ensure smooth rolling. In particular, manual control is difficult in a wide open field, where the automatic driving of rollers using our current system will improve the surface qualities and save labor. Automated press rolling work has long been demanded in view of the monotonous driving of an automatic press roller, the asphalt heat, and excessive vibration.

2) Earth auger

Frequent positioning is done in such work as grounds improvement and building foundations. For these types of work, poor ground conditions and difficult positioning make the work processes more complicated. The currently used procedure is to bury a string-attached iron rod into the position predetermined by a transit, and to set an earth auger after removing the rod by pulling the string when construction work begins. Automated positioning will eliminate these processes to save time and to improve efficiency.

3) Bulldozers

Levelling work includes raising an entire level and sloping the ground for a water grade. Work efficiency has been recently improved by automating blade control. The Laser Positioner could be used for greater automation geared toward unmanned bulldozer operation.

For making a water grade by sloping an area that rises in the middle, both positioning and levelling could be simplified by combining the current system with a laser leveller for automatic, precise, and time-saving operations.

(See Fig. 6.)

4-3 Proposal positioning robot applications

Self-driven positioning robots can be used for around and floor work positioning (see Fig. 7). By transmitting CAD data to such robots, an actual size drawing of the ground can be obtained before construction. In addition, unmanned equipment operations may be possible even at night, which would significantly reduce the time required for construction work.

Ideally, these robots can be used to plot curves when surveying. The current procedure for surveying with a transit and tape measure is based on right angles and linear lines, and requires much labor. A positioning robot, however, could make direct curvature surveying possible.

References

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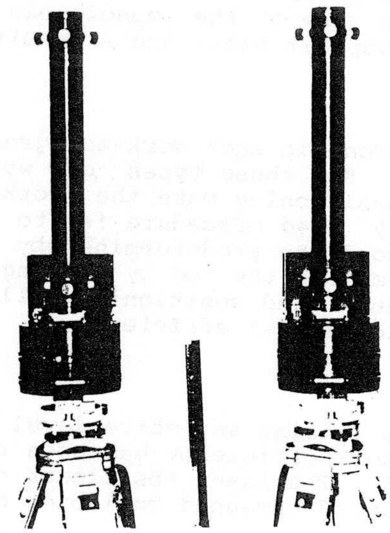
(2) Kouhei Mio and Tatsuyuki Ochi: "Automating and Robotizing Construction Equipment with the Laser Positioner," Symposium on Construction Equipment and Procedure," 1987



Photograph 1 Positioning system with two laser beacons and photosensor

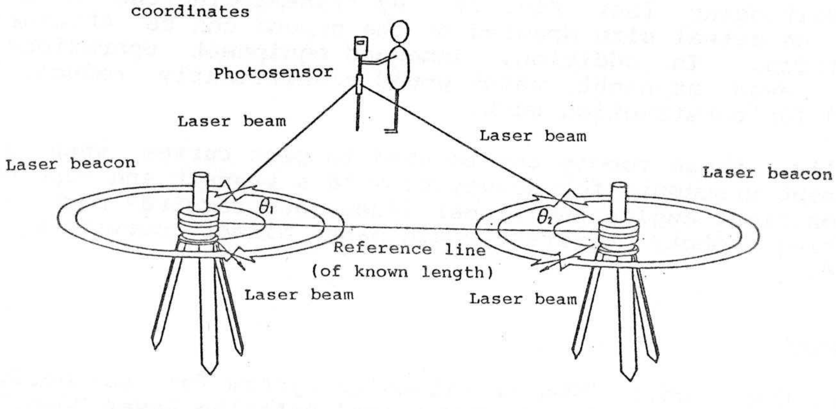


Fig. 1 Configuration of system devices

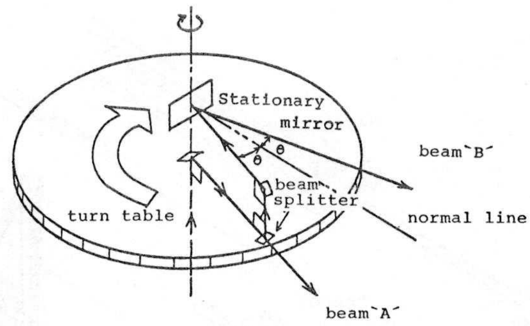


Fig. 2 Symmetrical rotating laser beams

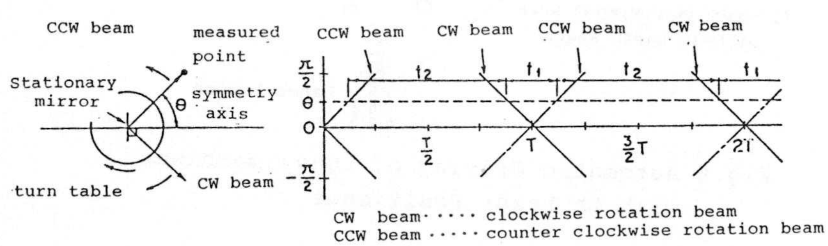


Fig. 3 Angle-detected interval

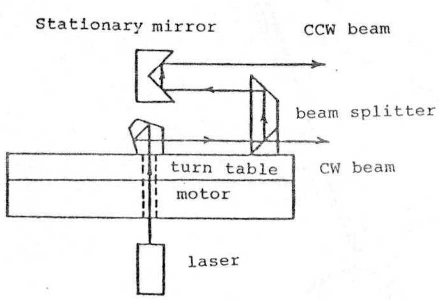


Fig. 4 Optical composition of trial system

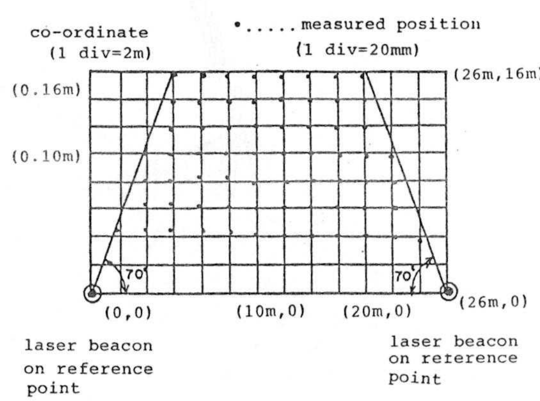


Fig. 5 Result of the experiment

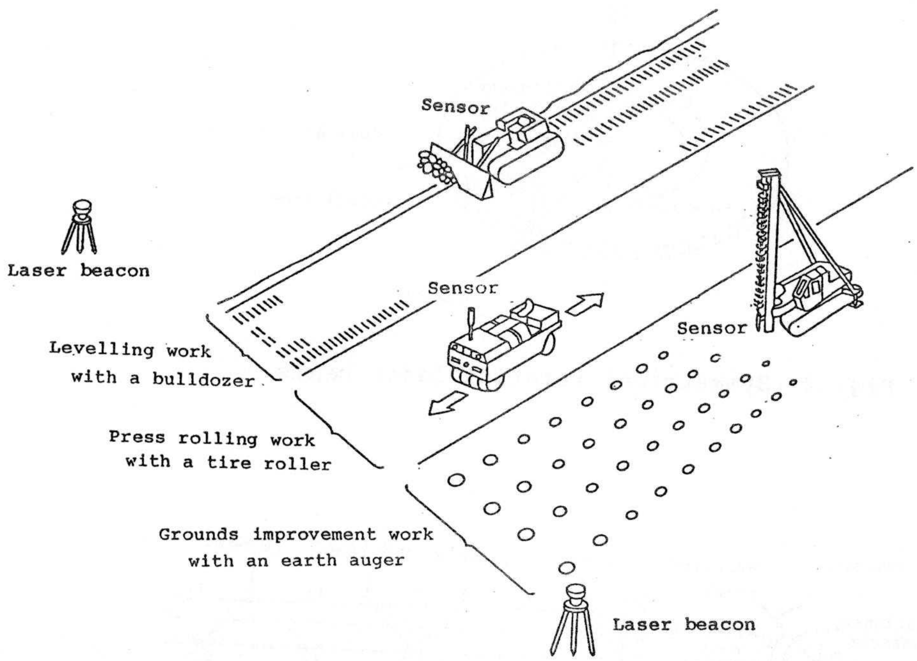


Fig.6 Automatic driving of heavy machines
with th Laser Positioner

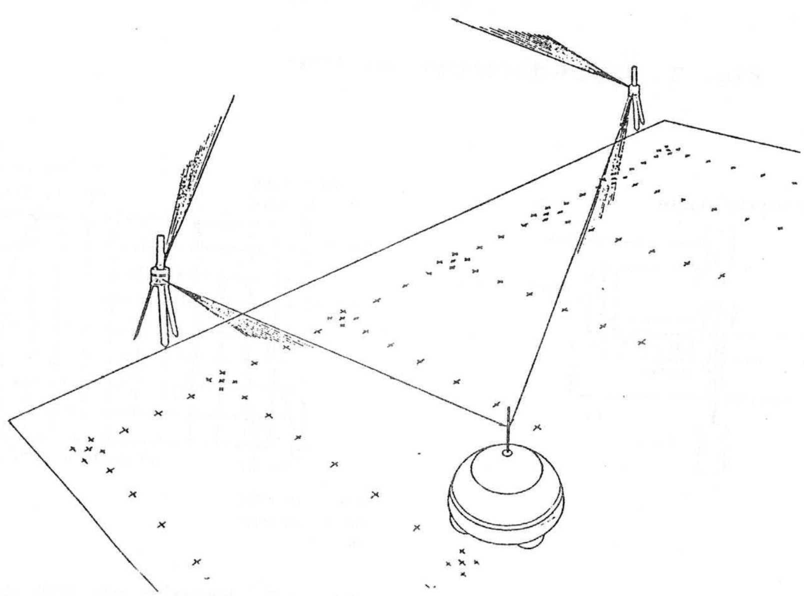


Fig. 7 Self-driven positioning robot