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3-D Measuring System for Large Structures

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Abstract:

A system to measure 3-dimensional coordinates of large structures is presented in this paper. In order to enable accurate measurements calibration of the measuring system is important.Feature of our system are that by introducting one simplified calibration procedures setting of the measuring system is simplified and also that tracking performance is increased. An experimental result reveals the applicability of our system.

1 Introduction

Nowadays 3-dimensional measuring techniques like streometric methods, Moire interference fringe pattern methods and laser range finder methods are presented. while these techniques enable 3-D measurements, many problems occurs if the size of the target body overs a few meters;e.g. buildings, ships and tanks. One powerful technique to answer these problems is a wellknown methods to measure points on the target body using two latest surveying instruments called transits or theodolites, based on the principle of trigonometric survey. In order to realize this system as a more practical 3-D measuring system, all manual tasks needs to be replaced with computer control. Previously we proposed one example as an automatic 3-D measuring system. Two important units of our system are one Spot-Ray-Pointer and one Spot-Ray-Tracker, those are more compact, more suitable for computer control and less expensive than latest surveying instruments. The Spot-Ray-Pointer is controlled to project laser beam in the pre-programmed directions. Whereas, the Spot-Ray-Tracker is controlled to detect the direction of the laser spot. Accounting the direction of the Spot-Ray-Pointer and the Spot-Ray-Tracker, 3-dimensional coordinates of the laser spot on the target body can be determined. The system already proposed enabled accurate measurement. However, setting and calibrating the measuring system was cumbersome and spent lots of time.

In this paper we propose a new 3-D measuring system which enables more easy setting and calibration. Using our new system, setting of the measuring system needs not to be accurate and calibration can be executed just by measuring the scale bar located at different positions.

An experimental result to test the accuracy and applicability of our system indicates that out system has good performances.

2 3-D Measuring System

The setup of our 3-dimensional measuring system is shown in Fig.1. This system consists of Spot-Ray-Pointer, Spot-Ray-Tracker and system controller. The Spot-Ray-Pointer and the Spot-Ray-Tracker is shown in Photo.1. On the Spot-Ray-Pointer a laser emitting tube wit a wave length of 632.8 [nm] with emitting power 10[mW] is mounted. The laser beam is reflected with two mirrors whose ratating angle is controlled with fine-step motors (0.0072 degree per one step) to project the laser spot with 2mm diameter in the pre-specified direction. A Spot-Ray-Tracker is used to detect the direction of the laser spot on the target body. As is shown in Fig.1, at the end of a sighting elescope, one CCD TV camera is mounted. The orientation of the sighting telescope is controlled by the same mechanism with the Spot-Ray-Pointer. Mechanical movements are only rotations of two mirrors. Therefore, high mechanical accuracy of the whole system and fast 3-D measurements became possible. Four step motors in this system have a high resolution since harmonic derive reduction mechanisms are employed. Since rotational errors caused by these mechanisms affect accuracy of the measurements, our system employs laser rotary encoders on every raotating axis of the mirrors. The rotating accuracy is 0.278E-4 [degree]. The Spot-Ray-Pointer and the Spot-Ray-Tracker are independently

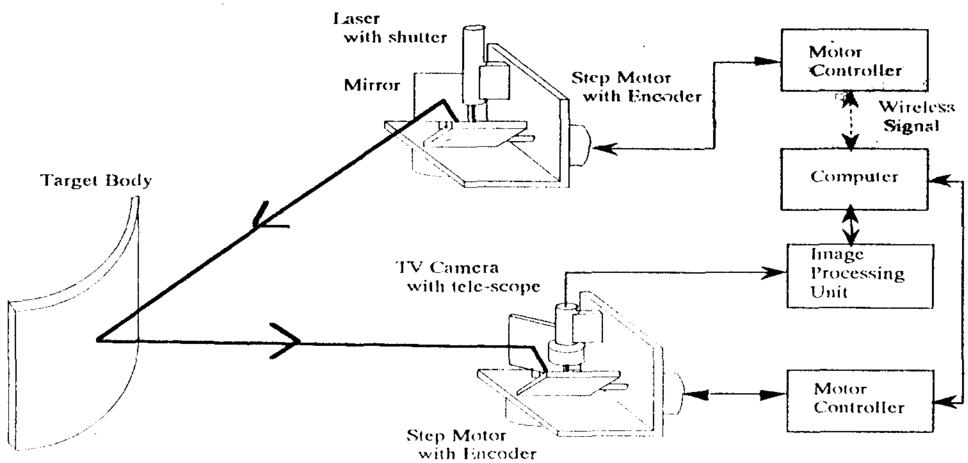

Fig.1 System Setup

controlled with two motor controllers, which communicate with the other by wireless signal to expand the distance between the Spot-Ray-Pointer and the Spot-Ray-Tracker.

In order to measure the 3-dimensional coordinates based on the principle of triangulation, we need to measure the orientation of the laser emitted from the Spot-Ray-Pointer and the orientation of the laser spot detected with the Spot-Ray-Tracker. The orientation of the laser spot determined by the orientation of the Spot-Ray-Tracker and raster coordinates of the gravity center of the laser spot on the image plane detected by the CCD TV. It should be noted that while the orentations of the Spot-Ray-Pointer are pre-programmed, orientations of the Spot-Ray-Tracker need to be controlled considering the orientation of the Spot-Ray-Tracker and also raster coordinates of the gravity center of the laser spot.

An image processing unit performs 8-bit gray scale image data processing with 512*480 pixels per frame obtained by the CCD TV camera, and gives raster coordinates of the gravity center of the laser spot. In order to reduce the error caused by the hazardous lighting environments, a mechanical shutter to interrupt the laser spot beam is mounted on the Spot-Ray-Pointer and a image-subtraction technique is used. The raster coordinates of the center of the laser spot is obtained as follows.

First, closing the mechanical shutter, the background image without emission of laser is stored into the frame memory. Next, the laser beam is emitted and the laser spot image is stored into frame memory. Immediately after that, subtracting the first image from the second image, the image processing unit obtains raster coordinates of the center of the laser spot without any effects of background image.

3 Determination of 3-D Coordinates

On determining the 3-D coordinates of target points, the geometrical setup of the Spot-Ray-Pointer and the Spot-Ray-Tracker should be calibrated in advance.

Calibration

Based on a minimum squared-error technique, measurements of a scale bar located at more than four distinguished positions realize the calibrating process. We summarize those results briefly.

Let world coordinates of a target point be x,y,z and the corresponding azimuth and elevation angles be θ and ϕ which are obtained by the Spot-Ray-Pointer and the Spot-Ray-Tracker. Due to the principle of perspective transformation, the following equation establishes,

$$\lambda \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \\ 1 \end{bmatrix} \qquad (1)$$

where u and v represent $\tan\theta$ and $\tan\phi$ respectively, and elements h_{ij} represent the geometrical relationship.

One calibrated scale bar is used to calibrate the geometrical relaton of the system setting. The following procedure is how the calibration is executed.

1) The Spot-Ray-Pointer and the Spot-Ray-Tracker are settled so that the target can be measured with accuracy.

A desirable allocation of the system should be decided considering results of the error analysis. However, the setting of the system needs not to be accurate since calibration results compensates the setting errors.

2) Locate the calibrated scale bar near the target to be measured. And measure the orientations of the both ends of the scale bar using the Spot-Ray-Pointer and the Spot-Ray-Tracker.

Let coordinates of the both ends of the bar be (x_1,y_1,z_1) and (x_2,y_2,z_2),the following equation is satisfied

$$L=\sqrt{(x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2} \qquad (2)$$

where L is length of the calibrated scale bar.

It is important to note that the date which are obtained by measuring the both ends of scale bar should satisfy Eq.(1) and (2). Considering the above fact and also the number of unknown variables to be calibrated, it is a matter of fact that measurements of the scale bar located at four different positions determine the parameters h_{ij} in the minimum squared error meaning. However, the base coordinates of the system should be specified in advance. In our system we set the base coordinate coincides with the coordinate fixed on the Spot-Ray-Pointer.

The parameters h_{ij} can be calculated by a nonlinear programming developed by Broyden, Fletcher, Goldfarb and Shanno.

Tracking of laser spot

Once geometrical arrangements of our system are calibrated, measurements of 3-D positions become possible. One important problem to realize an accurate and fast measurement is to adjust the orientation of the Spot-Ray-Tracker to detect the laser spot around the center of the tele-scope. In the worst case the Spot-Ray-Tracker often fails to detect the laser spot in the sight. In such a case, the Spot-Ray-Tracker needs to search the laser spot with rotating two mirrors.

Here,we introduce one technique to search the laser spot efficiently. Using vector matrix notations,Eq.(1) for the Spot-Ray-Pointer can be rearranged as follows.

$$Dx = b \qquad (3)$$

$$D=\begin{bmatrix} h_{31}u-h_{11} & h_{32}u-h_{12} & h_{33}u-h_{13} \\ h_{31}v-h_{21} & h_{32}v-h_{22} & h_{33}v-h_{23} \end{bmatrix},\ b=\begin{bmatrix} h_{14}-u \\ h_{24}-v \end{bmatrix}$$

Vector x to satisfy Eq.(3) can be represented by

$$x = g + f\ \varepsilon \qquad (4)$$

$$g = D^T(DD^T)^{-1}b,\quad f = d_1 \times d_2$$

where $D^T(DD^T)^{-1}$ is a pseudo inverse of matrix D, vector di is i-th column vector of D and ε is an indefinite scaler number.Since the laser spot lies on a line represented with Eq.(4), the orientation of the Spot-Ray-Tracker to search the laser spot can be limited as follows.

Substitution of Eq.(4) into Eq.(1) to represent the posture of the Spot-Ray-Tracker gives

$$\varepsilon = -\frac{(h_1-h_3u)^T g + h_{14}}{(h_1-h_3u)^T f} \qquad (5)$$

$$v = \frac{h_2^T(g+f\varepsilon)+h_{24}}{h_3^T(g+f\varepsilon)+1} \qquad (6)$$

$$h_1=\begin{bmatrix} h_{11} \\ h_{12} \\ h_{13} \end{bmatrix}\quad h_2=\begin{bmatrix} h_{21} \\ h_{22} \\ h_{23} \end{bmatrix}\quad h_3=\begin{bmatrix} h_{31} \\ h_{32} \\ h_{33} \end{bmatrix} \qquad (7)$$

where h_{ij} are parameters defined by Eq.(1) for the Spot-Ray-Tracker.

Eq.(4) means that once azimuth angle of Spot-Ray-Tracker is settled, parameter ε is determined. And once ε is determined, elevation angle ϕ of the Spot-Ray-Tracker to detect the laser spot is determined by Eq.(6) and x,y,z coordinates are determined by Eq(4).

This means that once azimuth angle θ or u(= $\tan\theta$) of the Spot-Ray-Tracker is settled, elevation angle ϕ or v(= $\tan\phi$) is automatically determined,

As a result, speed of tracking by the Spot-Ray-Tracker if highly increased and effects of unfavorable disturbance is can be rejected.

4. Experimental result

In order to set the applicability of our measuring system, we measured 3-D coordinates of points on a curved plate whose size is 2 meters x 1 meter. The Spot-Ray-Pointer and the Spot-Ray-Tracker are settled 8 meters apart from the target object and 3 meters apart from each other. Photo.1 shows the experimental result, where 1116 points of data are obtained. It takes about 20 minutes to measure this target object.

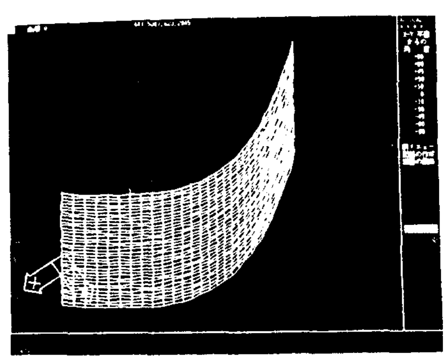

Photo.1 Experimental Result

5. Conclusion

A system to measure the 3-dimensional shape of large structures has been presented. Comparing the system we proposed previously, our new system employs a more easy calibrating methods. Following this new methods, measurements of scale bar located at four different positions enable to determine parameters which represent geometrical arrangements of the Spot-Ray-Pointer and the Spot-Ray-Tracker.
An experimental result showed that calibration procedures proposed are simplified remarkably.

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