'92 KACC 1992. 10. 19~21

On 3-D Measuring Technique of Large structures

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Abstract : We present a system to measure 3-dimensional coordinates of large structures such as ships, buildings and oil tanks. Our system consists of two important units which are a laser spot pointer and a laser spot tracker. Employing a tactful image processing, our system has some features:e.g. downsize, cost, accuracy and robustness to hazardous environments. enable accurate measurement of the direction of these units. A tactful image processing is performed on the laser tracker so that an accurate and fast 3-dimensional measurement can be realized. This system is applied to measurement of the 3-dimensional shape of a cylindrical object. Experimental results indicated that our system has enough performance.

1. Introduction

Today 3-dimensional measuring techniques such as stereometric method, Moire interference fringe pattern method and laser range finder method are presented [1]. While these techniques give us basic approaches to 3-D measurements, for the target body whose size overs a few meters several problem occur as follows. As environment around the target body is influenced by the lighting condition, these method cannot get good measurement accuracy. We already presented one measuring system of large structures [2]. However it still has some problems on the handling and the practicability. We improve this system so that it can be used in practical.

In this paper we show our newly developed system to enable 3-dimensional measurement of large structures whose sizes over a few meters. One feature of our system is that 3-dimensional measurement so that the shape of the large target body can be obtained automatically. Our system was consists of two main units. One is laser pointer to project laser spot ray on the target body, and the other one is laser tracker to detect and trace the laser spot on the target body by a CCD TV camera and a telescope. These two units realize 3-dimensional measurement based on the laser spot ray projection method or the trigonometry. The directions of these two units are controlled by the fine-step pulse motors. High precision rotary encoders

2. 3 -D Measuring System

The setup of our 3-dimensional measuring system is shown in Fig.1. This system consists of one laser spot projector, one laser spot tracker and a system controller. On the laser spot pointer a laser emitting tube at a wave length of 635 [nm] with 10 [mW] is mounted. The laser beam is reflected with two mirrors which are rotated with fine-step motors (0.0072 degree per one step) to project the laser spot with 2 mm diameter in the pre-specified direction. A laser spot 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 telescope, one CCD TV camera is mounted.

The orientation of the sighting telescope is controlled by the same mechanism with the laser spot projector. The mechanical movement is restricted to the rotation of two mirrors in order to achieve the high mechanical accuracy of the whole system and the fast measurements.

The step motor in this system has the high resolution since the harmonic derive reduction mechanisms is employed. However, rotational errors caused by the harmonic derive reduction mechanisms influence the final precision of the measurements.

Thus, our system employs the laser rotary encoder with the high resolution, which can detect the angle with the precision 0.278E-4 [degree].

The laser spot pointer and the laser spot tracker are controlled by different controller, respectively. Two controllers communicate each other by wireless signal

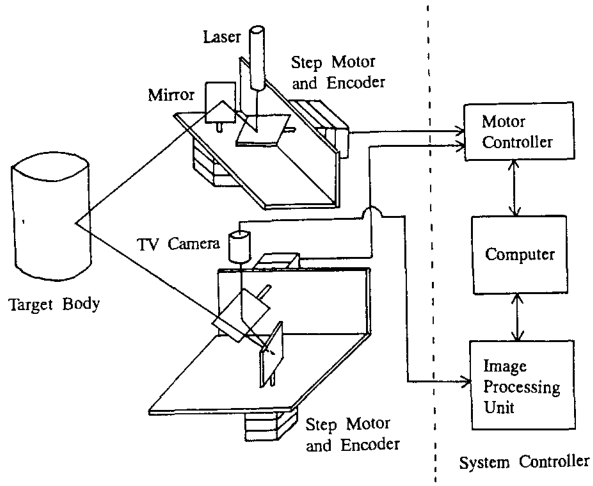

Fig.1 System Setup

in order to eliminate the limitation concerning to the distance between the laser spot pointer and the laser spot tracker.
The laser spot pointer and the laser spot tracker is shown in Photo.1.

In order to measure the 3-dimensional coordinates based by the principle of trigonometric survey, we need to measure the orientation of the laser spot projector and the orientation of the laser spot tracker. Computer calculates the coordinates of the laser spot on the target body form the data such as the orientation of the laser spot projector, the orientation of the laser spot tracker and the raster coordinates of the gravity center of the laser spot. It should be noted that it is necessary to control the orientation of the laser spot tracker around the center of the raster coordinates since the deviation of the orientation of the laser spot tracker can be easily calculated using 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 following image-subtraction technique is used. Suppose that the laser spot projector and the laser spot tracker are settled. First, an only background image without emission of laser is stored into the frame memory. Next, the laser beam is emitted. The laser spot image is stored into the frame memory. Subtracting the first image form the second image, the image processing unit obtains more stable detection of the center of the laser spot without any effects of background image.

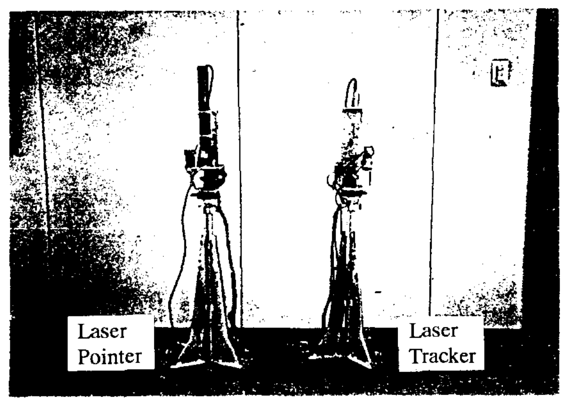

Photo.1 Laser Pointer and Laser Tracker

3. Determination of 3-D coordinates

The laser spot pointer and the laser spot tracker are set up as in Fig.2. The coordinate systems in Fig.2 are also introduced. From the angles of the mirrors θ_i, $\phi_i (i=1,2)$ the 3-dimensional coordinate of the target point is given by principle of trigonometric survey as follows.

$$x = L \times \frac{\tan\phi_2}{\tan\phi_1 + \tan\phi_2} \qquad (1)$$

$$y = L \times \frac{\tan\phi_1 \times \tan\phi_2}{\tan\phi_1 + \tan\phi_2} \qquad (2)$$

$$z = L \times \frac{\tan\phi_2 \times \tan\theta_1}{\left(\tan\phi_1 + \tan\phi_2\right) \times \cos\phi_1} \qquad (3)$$

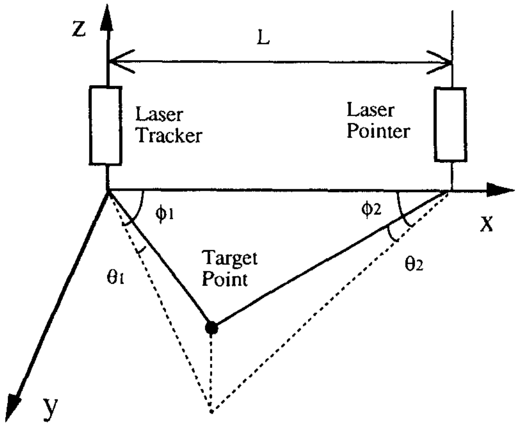

Fig.2 Position of Laser Tracker and Laser Pointer

In this measuring method the laser spot pointer projects the laser spot on the target body and the laser spot is detected by laser spot tracker. Since the laser spot tacker has two degrees of freedom θ_1 and ϕ_2 in the detection, the efficient measurement is needed. From Fig.2 a following equation is obtained.

$$z = L \times \frac{\tan\phi_2 \times \tan\theta_1}{(\tan\phi_1 + \tan\phi_2) \times \cos\phi_1} = L \times \frac{\tan\phi_1 \times \tan\theta_2}{(\tan\phi_1 + \tan\phi_2) \times \cos\phi_2} \qquad (4)$$

After several manipulations, we have a following equation.

$$\frac{\tan\theta_1}{\sin\phi_1} = \frac{\tan\theta_2}{\sin\phi_2} \qquad (5)$$

Eq.(5) gives the tracking condition of laser spot tracker: Here it is interesting to note that the orientation of the laser spot pointer (θ_2, ϕ_2) are settled the orientation of the laser spot tracker (θ_1, ϕ_1) satisfies Eq.(5). Therefore, if ϕ_1 be the angle of the laser spot tracker, the levitation angle θ_1 should be adjust to be;

$$\theta_1 = \tan^{-1}\left(\frac{\tan\theta_2}{\sin\phi_2 \times \sin\phi_1}\right) \qquad (6)$$

This relation simplifies the tracking of the laser spot tracker.

4. Detection of the Angle

We use the laser rotary encoder(CANNON,K1) to detect the angles of the mirrors precisely. This encoder arises 81,000 sine waves per one rotation. By analyzing the phase of the sine wave we can measure the angles of the mirrors with accuracy 0.278E-4 [degree].

Fig.3 shows the block diagram of angle detection circuit.

In Fig.3 the buffer is used to fetch the signal digitized to binary data of the phase A of the encoder. The binary data compensates the phase of the sine wave which is obtained by A/D converted signal and the frequency data that is counted by frequency counter.

5. Experimental result

In order to test the utility of our measuring system, we measured 3-D coordinates of a cylindrical object whose diameter is 40 [cm]. The laser spot pointer and the laser spot tracker are settled 8 meters apart from the target object and 2 meters apart from each other. Fig.4 shows the experimental results, which 4,000 points of data are obtained. It takes about 20 minutes to measure the target object. The maximum absolute error in position keeps less than 1 mil meters.

6. Conclusion

A system to measure 3-dimensional shape of large structures has been presented. Comparing with the system we proposed in [3] , our new system is improved as follows.

1. By reducing the mechanical moving parts as much as possible, our system can perform fast measurement and achieve high accuracy with low cost.

2.We could improve the accuracy by employing the laser rotary encoder which has high accuracy.

We measured a cylindrical object with 2 meters height, which is settled 8 meters apart from the laser spot pointer and the laser spot tracker. It was possible to measure this target twice in one second and to keep the maximum absolute error in position less than 1 mil meters. As a subject for a future study, we shall intend to measure the target ten times in one second by high speed image processing.

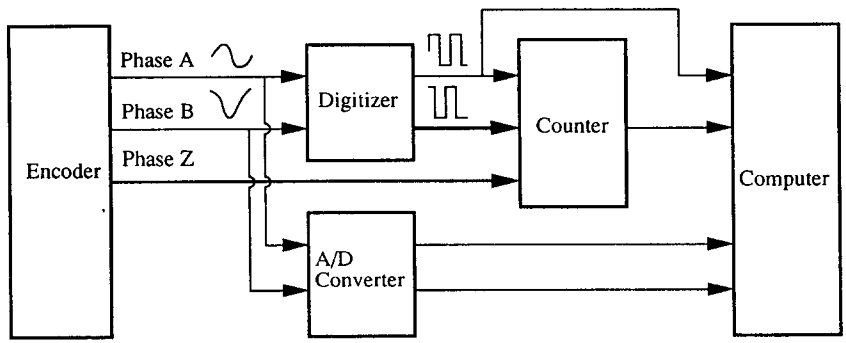

Fig.3 Block diagram of angle determination

References

[1] M.J.Margee,et al.: Using Multisensory Image to Drive the Structures of Three-Dimensional Objects, A Review, CVGIP, 32, 147/157(1985)
[2] T.Ishimatsu, et al.: 3-D Measuring System of Structure and Pressure Vessels, Proc. of KACC ,vol.2, 987/992, 1989
[3] T.Ishimatsu, et al.: 3-D Measuring System of Huge Structures using Laser Spot-Ray Projection, Proc. of KACC, vol.2 1162/1166, 1990