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Three-Dimensional Shape Measurement using Grating Patterns from an Optical Spatial Modulator

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Abstract

An automatic measuring system of three dimensional shape by a projection method with grating pattern from an optical spatial modulator has been developed. The characteristics of the system were studied. This system is composed of a projector, an optical spatial modulator,a CCD camera,and a computer. A liquid crystal is used as the optical spatial modulator. The grating patterns that are projected on the surface of the object are controlled by the computer connected with the optical spatial modulator. The projector patterns are measured by the CCD camera. The data are transferred to the computer. After a transformation into line data, the data are analyzed to obtain the coordinate of the surface of the object.

This system has advantages as follows. (1)It is possible to capture the surface topography without any contact. (2)The time required for the measurements is shorter than the light-section method. (3)An optical spatial modulator using a liquid crystal is possible to control the grating patterns accurately by a computer.

Surfaces of a plate and a cylinder were measured. The threshold level had an influence on the measurement. It was shown that this system has adequate accuracy in the measurements.

1. Introduction

Non-contact measurement of the three dimensional shape of an object is required in many fields. In the past, numerous reports have been made on such measurement, especially on methods that use optical devices. There are three methods of measurement.

One is a method described as follows: a laser beam is applied on the surface of a object, and the positions of the laser beam spots are detected by various detectors. Although the principle of this method is simple, the method has a defect of that the measurement requier a long time. To improve this defect, other methods have been developed. The light-section method is the one. The measuring time on the line is reduced in this method, but the time in the direction perpendicular to the line is not reduced.

A pattern projection method utilizes a pattern. In this method, a pattern is projected on the entire surface of the object. The projected pattern is detected by a CCD camera, and measurement is finished in a short time.

This is the most prominent feature of this method comparing to the other methods. At present, a grating pattern projection method is suggested as one this method.

In the grating pattern projection method, a grating pattern is projected on the surface of a object. The grating pattern projected on the object is detected by CCD camera. The three dimensional coordinate of the object is obtained through the transformation of the detected data. One of the stripes is decided as a datum stripe. The datum stripe and other stripes are called "0-th" degree and "n-th" degree, respectively.

In this method,the degree of stripes should be determined.The pattern needs to be controlled so that the datum strope can be recognized. In many cases, the grating patterns have been projected by slide projectors for such pattern control.

Instead of this method, this paper proposes a grating pattern projection method which uses a liquid crystal as an optical spatial modulator. By using a liquid crystal, the projection pattern is easily controlled. Also, this method has the advantage that pattern positioning accuracy does not decrease because mechanical operation is not necessary. In this paper, we describe the construction of a three dimensional shape measurement system which utilizes a liquid crystal as an optical spatial modulator instead of other methods. The results of the shape measurements of objects are also discussed with experiment of pattern positioning accuracy.

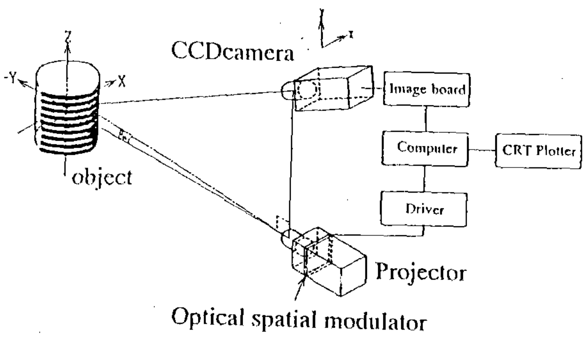


Fig.1 Three dimensional shape measurement system

2. Three Dimensional Shape Measurement System

Figure 1 shows the three dimensional shape measurement system based on the grating pattern projection method. The system consists of a projector, a CCD camera, an image board and a computer. The system was set up using an optical spatial modulator,instead of the traditional slide projector for projecting the pattern on the object. A computer-controlled monochrome liquid crystal was used as an optical spatial modulator. The measuring principle was based upon the triangulation method. A grating pattern on the horizontal direction was created on the liquid crystal, that is, on the optical spatial modulator. Using the projector, a pattern on the liquid crystal is projected on the surface of the object. The CCD camera, set in the vertical direction against the pattern, took the image. In this process, the distortion of the pattern appeared in accordance with the shape of the surface of the object. An analog video output signal is stored in a frame memory. Next, the image in the frame memory is transfered to the computer, and image processing such as the binary operation, the thin line operation, and three dimensional coordinates transformation were carried out. Finally, the shape of the measurement object was displayed as a wire frame model.

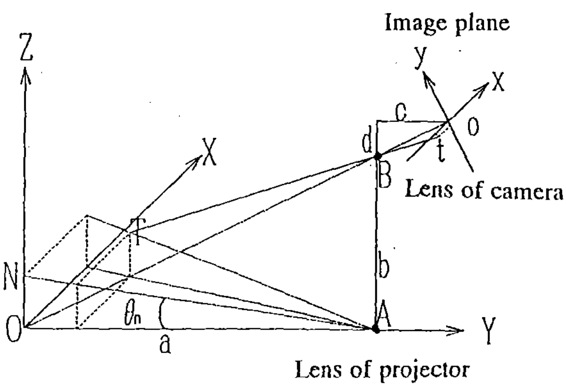


Fig.2 Arrangement of the optical system

Figure 2 shows the arrangement of the optical system. X-Y-Z are coordinates of the object, and x-y are coordinates on the image plane.The image plane is the surface of the CCD. The optical axis of the projector is Y axis. The distance from the projector to the origin of the coordinate axes of the object is "a". The distance from the projector to the center of camera lens is "b". "c" and "d" are the distance from the center of the camera lens to the image plane. "θ n" is the angle between the edge of datum stripe and edge of n-th stripe.

equiation 1 shows the transformation inthe frame memory to the three dimensional coordinates.

$$X=(b\sqrt{a^2+b^2}\,x)/H$$
$$Y=\{(mab\sqrt{a^2+b^2}+b^2y)\tan\theta_n-(a^2+b^2)y\}/H$$
$$Z=\{(-ma\sqrt{a^2+b^2}-by)\tan\theta_n+(a^2+b^2)y\}/H$$
$$H=(ma\sqrt{a^2+b^2}-by)\tan\theta_n+mb\sqrt{a^2+b^2}+ay$$
$$m=c/a=d/b$$

Equation 1 Three dimensional coordinate transformation

3. Image Processing

3.1 Decision of the threshold

Figure 3 shows the projection pattern when the line section(dark section) and the space section(bright section) were each projected with the width of two pixels. Because the liquid crystal frame is regarded as the line section,the ratio between the line section and the space section was 0.53 to 0.47. In order to examine the influence of the liquid crystal frame, a flat plate was placed on the X-Y coordinate plane, and the pattern was measured.

Figure 4 shows the intensity distribution on the camera. (This corresponds to the scanning line shown in figure 3.) The threshold value for binary operation was set to around 60. the width of line section is about 10% wider than the space section. A large difference of width between the line section and the space section influenced θ n (the angle

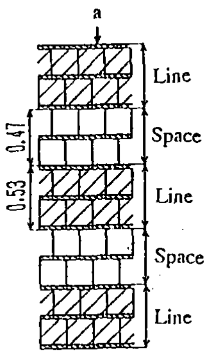


Fig.3 Liquid crystal display

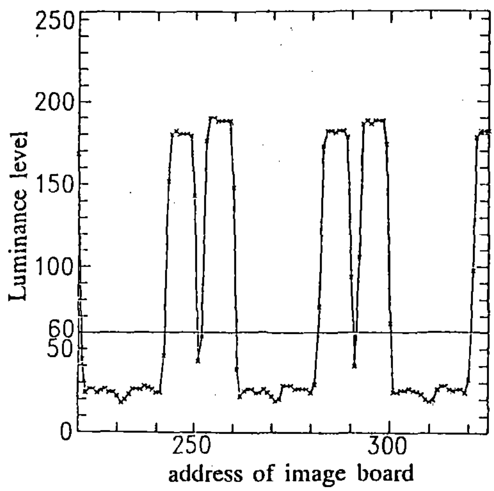


Fig.4 Intensity distribution on CCD camera

made between the Y axis and the n-th stripe) of three dimensional coordinate transformation in equation 1, thus causing a problem in coodinate transformation. Therefore, the difference between the line section and the space section must be made equal. However, it is difficult because of the existence of the liquid crystal frame. The influence is small, when the difference between the pattern section and the space section was under 10 %.

3.2 Image Processing

Figure 5 shows the diagram of the image processing. The image processing is carried out by decision of the datum stripe, input of the deformed pattern, binary operation, thin line operation, conversion and display. In the binary operation section, the pattern is analyzed, and the binary operation is carried out by using the "threshold value" obtained previously. In the thin line operation section, the border between the space section and the line section is detected as an edge. The data are transformed to conversion section from thin line operation section. The degree of the stripes are recognized in order to increasing the number of the degree based on the datum stripe (0-th degree stripe). Finally, the three dimensional coordinate was transformed by using equation 1. In the display section, the shape of the measured object was displayed as a wire frame model.

4. Result of Measurement

4.1 Flat object

Figure 6 shows the result of binary operation and thin line operation in image processing, when a flat object was

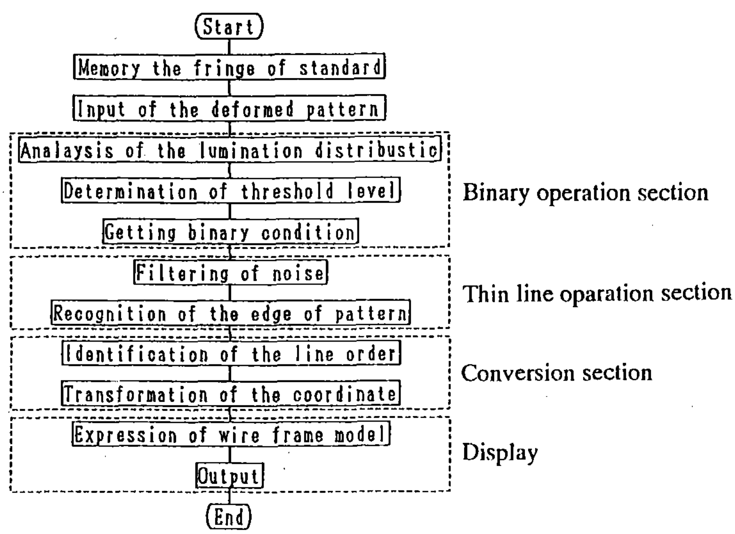
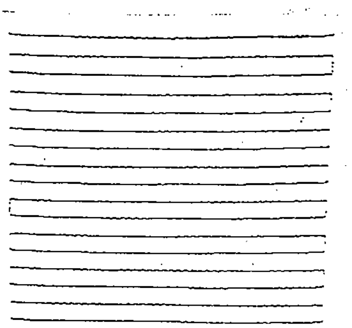


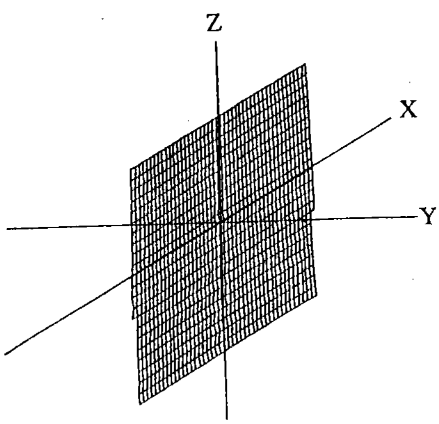
Fig.5 Diagram of the image processing

placed on the X–Z plane. From the result of figure 6 in the binary operation, the influence of the liquid crystal frame was observed in the space section. However, the influence was not observed in the thin line operation. In figure 7, measurement was made at Y=2,0,–2 cm, and the cross section of –3rd,0th,3rd degrees are shown. The each stripe was observed correctly at Y=2,0,–2 cm. The irregularities was the error in the binary operation.

(a)Binary operation

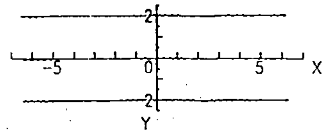


(b)Thin line operation

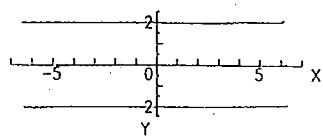


(c)Wire frame model

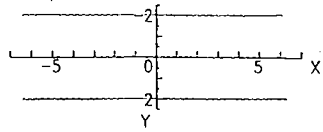
Fig.6 Result of measuring a flat object



(a)The cross section of –3rd degree



(b)The cross section of 0th degree



(c)The cross section of 3rd degree

Fig.7 Cross section of result of measuring a flat object

4.2 Cylinder object

In figure 8 and 9, the result of measureing a cylinder with a radius of 5 cm is indicated in the form of wire frame model and the cross sections. The maximum error in the radius was 4 %.

4.3 Pattern Positioning Accuracy

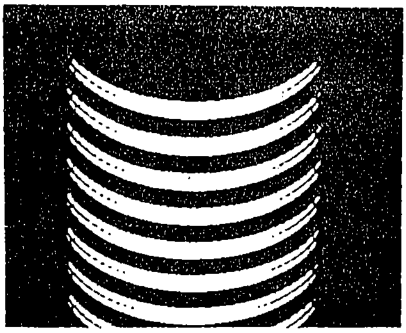
To examine the positioning accuracy, the pattern projected by the projector and 0–th degree stripe drawn on the object was detected by CCD camera. Figure 10 shows the result. It was confirmed that the pattern positioning was accurate.

5. Conclusion

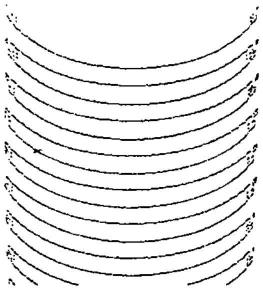
In this paper,we described a pattern projection method which uses a liquid crystal as an optical spatial modulator. It was demonstrated that it was possible to measure the shape of a object using this syatem. The accuracy of the measurements was improved by using the edge of the stripes. In addition, the pattern positioning is highly accurate

Referrences

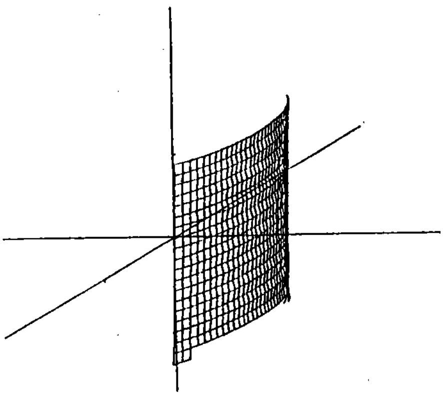
1. T.Yoshizawa and K.Suzuki, Automatic 3D Measurement of Shape by Grating Projection Method, JSPE–53–03(1987)
2. M.Takeda and K.mutoh, Fourier Transform Profilometry for The Automatic Measurement of 3–D object shapes, Appl.Opt.22–3977(1983)



(a)Binary operation



(b)Thin line operation



(c)Wire frame model

Fig 8 Result of measuring a cylinder with a radius of 5cm

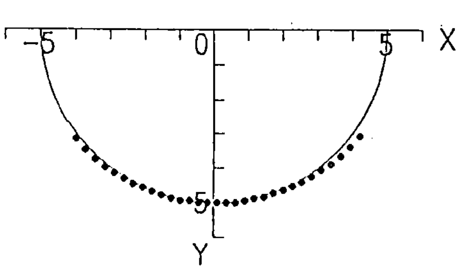


Fig.9 Cross section of result of measuring a cylinder

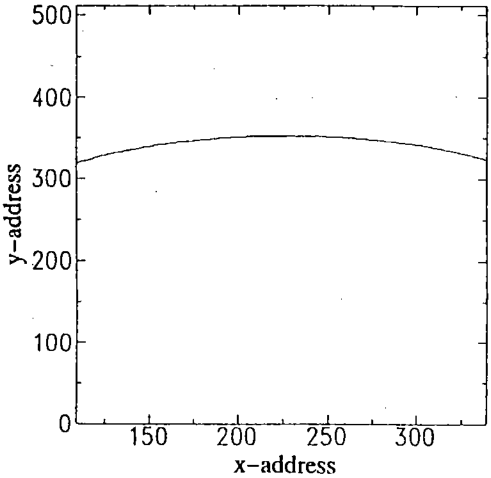


Fig.10 Accuracy of Pattern positioning