Development of Shape Measurement System Using Mirrors for Metallic Objects

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Abstract

3-D shape measurement systems by contactless method are required in the quality inspections of metal molds and electronic parts in industrial fields. A grating projection method with phase analysis has advantages of high precision and high speed. Halation often occurs on a part of a metallic object. When the direction of the camera or the direction of the projector is changed, the halation area is changed. It is, therefore, possible to decrease the influence of the halation using several cameras[7]. The results obtained by the several cameras are the same coordination system because the same reference planes are used for the calibration in the WSTM. Therefore, it is easily to merge the results obtained by the several cameras.

In this paper, we develop a shape measurement system with several cameras and mirrors to reduce halation of a metallic object. The mirrors are used to reduce the number of the cameras. The real and mirror images of an object are taken as an image by a camera. The calibration process for the mirror image of the object is the same as the real image because the mirror reference planes can be used. The developed system and the experimental results to measure a metallic object are shown.

Key words

3-D Shape Measurement, Whole-Space Tabulation Method, Metallic Object, Mirror, Several Cameras, Halation

1. Introduction

3-D shape measurement systems by contactless method are required in the quality inspections of metal molds and electronic parts in industrial fields. A grating projection method with phase analysis has advantages of high precision and high speed.

The calibration method is important for accurate shape measurement. In most conventional shape measurement methods, the optical system is modeled, and the parameters of the model are obtained with a calibration process. However, the model cannot contain all of the information about the optical system, such as the lens distortion or the intensity of the warping of the projected grating from a sinusoidal wave. The differences cause measurement errors. Furthermore, it takes a long time to calculate the spatial coordinates using the parameters. Therefore, several methods using a reference plane or reference planes have been proposed for accurate shape measurement [1, 2]. We previously proposed calibration methods that use two or more reference planes [3, 4].

A whole-space tabulation method (WSTM) [5, 6] developed by authors also contributes to the precision enhancement and speed-up. It is easy to compose the results of shape measurement obtained with the several cameras placed at the different positions because the 3D coordinates can be obtained on the same coordinate system.

Halation often occurs on a part of a metallic object. When the direction of the camera or the direction of the projector is changed, the halation area is changed. It is, therefore, possible to decrease the influence of the halation using several cameras[7]. The results obtained by the several cameras are the same coordination system because the same reference planes are used for the calibration in the WSTM. Therefore, it is easily to merge the results obtained by the several cameras.

In this paper, we develop a shape measurement system with several cameras and mirrors to reduce halation of a metallic object. The mirrors are used to reduce the number of the cameras. The real and mirror images of an object are taken as an image by a camera. The calibration process for the mirror image of the object is the same as the real image because the mirror reference planes can be used. The developed system and the experimental results to measure a metallic object are shown.

2. Whole-Space Tabulation Method

We propose a calibration method for an accurate and high-speed shape measurement using multiple reference planes with a 2-D grating fixed on the surface. Figure 1(a) shows the principle of the calibration method. The reference plane oriented vertically to the z-direction is translated in the z-direction by small amount. A camera and a projector are arranged and fixed above the reference plane. The grating is projected from the projector onto the reference planes. The grating is not required to have a regular pitch spatially. The phase of the projected grating can be easily obtained using the phase-shifting method mentioned above. A pixel of the camera takes an image on the ray line L in Figure 1(a). The pixel contains images of the points P₀, P₁, P₂...PN on the reference planes R₀, R₁, R₂...RN, respectively. At each point, the grating phases θ₀, θ₁, θ₂...θN can be calculated by the phase-shifting method. Therefore, the correspondence between the heights z₀, z₁, z₂...zN and the phases θ₀, θ₁, θ₂...θN is obtained.

Figure 1(b) shows the principle used to calibrate the x and y coordinates using multiple reference planes with a 2-D grating fixed on the surface. The 2-D grating has a regular pitch. The unwrapped 2-D phases of the 2-D grating, therefore, correspond with the x and y coordinates. So, the correspondence between the x, y and z coordinates on each reference plane at the pixel imaged along the line L can be obtained. 3-D coordinates of a point on the object can be acquired quickly using the phase-coordinate tables obtained by the calibration method mentioned above. The coordinates of each table element are produced with interpolation. When the phase of an object is obtained, the
table element number is obtained by dividing the phase by the phase interval of the table.

This method excludes a lens distortion and the intensity warping of the projected grating from measurement results theoretically.

Figure 2 shows an optical setup of shape measurement using a mirror. Two images of point Q can be taken by two pixels of a camera from different directions. One of the two pixels takes an image of point Q on a ray line \( L_1 \). The other one takes an image of point Q on a ray line \( L_2' \). Line \( L_2' \) is a mirrored line of line \( L_2 \). In the mirror image, there are a mirrored grating pattern, mirrored reference planes and mirrored object as shown in Fig. 2. A phase-coordinate table along the mirrored line \( L_2' \) can be obtained easily using mirrored reference planes.

Halation often occurs on a part of a metallic object. When the direction of the camera or the direction of the projector is changed, the halation area is changed. In the case of the optical setup shown in Fig. 2, the images at each point on the object can be taken from two directions. It is, therefore, possible to decrease the influence of the halation. The results obtained by the real camera and mirror camera are the same coordinate system because the same reference planes are used for the calibration in the WSTM. Therefore, it is easily to merge the results.

![Fig. 1 Principle of the calibration method using multiple reference planes](image1)

![Fig. 2 Optical setup of shape measurement using a mirror](image2)

### 3. Measurement Equipment Using Mirrors

The composition of the measurement equipment is shown in Figure 3. A grating projector is placed above a reference plane. The projector has a LED light source and a glass plate of a grating pattern. The angle of the grating pattern is set in 45 degrees from the \( z \)-axis. The grating pattern is projected with defocusing. The pitch of the projected grating is around 0.5 mm on the reference plane. The phase of the projected grating can be shifted precisely by a PZT stage.

The reference plane is a polished opal glass. Two ronchi grating plates with different directions are piled with the opal glass plate as shown in Fig. 3(a). A light source is placed under the two ronchi grating plates. The light source is turned on when the calibration for \( x \) - and \( y \)-directions. 2-D grating is projected from the back side of the reference plane as a fixed 2-D grating. A unit of the reference plane and the light source is placed on a \( z \) linear stage that the positioning precision is 0.1 \( \mu \)m.

Two cameras and two mirrors are located 90 degrees apart on the \( x \)-\( y \) plane as shown in Fig. 3(a). The angle of the cameras is 45 degrees in the vertical direction. They make it possible to take both the real image and the mirror image of the reference plane and an object. The WSTM can be apply to the mirror image. Figure 4 shows an example of the mirrors and a specimen projected grating. Four results of
shape measurement obtained from these two cameras can be
merged with a phase reliability evaluation value and a re-
sampling method [7]. If halation occurs, the phase
reliability evaluation value becomes low. The merged
result coordinates are obtained with averaging operation of
four results taken by four directional cameras with the
exception of the direction at which the phase reliability
evaluation value is low.

![Diagram of shape measurement system]

Fig. 3 Developed shape measurement system

![Diagram of measurement setup]

Fig. 4 Mirrors and a specimen projected grating

4. Experiments and Result
An experiment was performed using the developed shape
measurement system. The reference plane was used for the
specimen. The number of phase shifting was 4 for a period.
The reference plane was place from 100 µm to 900 µm
at the intervals of 100 µm. Figure 5 shows the results of
the height distribution along a center line of the specimen.
Error means a difference between the position of the
reference plane and the measured height. The average of
errors at each position is shown in Fig. 5. The standard
deviation calculated from the measured height distributions
along the center line at each position is also shown in Fig.
5. The average of errors at each position was less than 1
µm and the standard deviation at each position was less
than 2 µm. Any distortions can not be appeared.

Figures 6, 7 and 8 show an experimental result of a
shape measurement of a coin as a metallic object. Figures 6
shows grating images and the measured height distributions
of the coin taken by camera 1. Figures 7 shows grating
images and the measured height distributions of the coin
taken by camera 2. The typical areas of halation are
indicated with arrows in Figs. 6 and 7. Figure 8 shows the
height distribution produced from the height distributions in
Figs. 6 and 7. Figure 8 shows the good result on the whole
area in spite of several halation parts appearing on the
grating images shown in Figs. 6 and 7.
5. Conclusions
In this paper, a developed shape measurement system with two cameras and two mirrors to reduce halation of a metallic object was shown. The experimental results of shape measurements of a plate and a coin were shown. This system can measure the shape accurately and the effectiveness to reduce halation was confirmed.

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References