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3-D SHAPE MEASUREMENT BY EXTRACTION OF CHARACTERISTICS USING IMAGE PROCESSING

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ABSTRACT

Two methods for measuring shapes of objects are proposed. One is for convex shape measurement, the other is for cylindrical shape. These methods are based on the slit-ray projection method. A thin slit beam light emitted from a laser is projected onto the surface of an object. By moving or rotating an object and recording the images, a three-dimensional image is constructed. Although conventional analysis of a three-dimensional image requires large memory space and long processing time. This proposed method reduces memory space and processing time. Only two two-dimensional frame memories are required. One is the memory for recording a characteristic value such as the maximum brightness in each pixel. The other is for recording a datum such as the displacement of the object table or the rotating angle of the object table when the pixel point has the characteristic value.

1 INTRODUCTION

In recent years, the interest in three-dimensional shape measurement of objects has been increasing in many industrial applications such as robot vision, computer-aided design, apparel design, deformation analysis, and so on [1]~[4]. 3-D shape measurement is very important and useful in such fields. Many techniques have been developed for obtaining 3-D shapes using image processing.

The slit-ray projection method is one of the most available one [2][3][4]. Using this method, 3-D information of the shape can be obtained with simple calculation. The conventional slit-ray projection method, however, still have fundamental problems. One of them is that information of the shape can be obtained only on the projected line of the slit ray. To measure the shape of the full surface, many images are taken and a three-dimensional image composed of them is analyzed. Araki et al. [3] developed a special position sensor array to detect in high speed the position of the projected slit ray. It is, however, very expensive. If the conventional CCD camera is used, it requires large memory space and long processing time. However, it is not always necessary for all of the data to be kept for a long time. If only necessities are extracted from them, the requisite memory space and processing time can be reduced, and the information of the shape can be obtained more minutely. Uesugi et al. [2] developed a 3-D shape measurement system using an image encoder by checking the maximum brightness on each pixel point. The memory space and calculation time is reduced.

In this paper, the idea is generalized and expanded to the convex shape and cylindrical shape measurement.

2 THEORY OF EXTRACTION OF CHARACTERISTICS

Let us consider a shape measurement method based on the slit-ray projection method. The geometric relation of the setup for it is shown in Fig.1. A horizontal thin slit beam light emitted from a laser is projected onto the surface of an object. The thresholding and thinning of the image of the beam light obtained by a CCD camera with a vertical optical axis gives a contour line of the z-direction of the object. By moving the object table along the vertical axis i.e. z axis and recording the images, many contour lines of the object which show the shape of the object are obtained. In conventional shape measurement, all of the images are recorded and analyzed as a three-dimensional image, so it requires large memory space and long processing time.

In this paper, a new image processing method by extraction of characteristics is proposed for these measurement. An example for a three-dimensional shape analysis is shown in Fig.2 . The system consists of a CCD camera, an object table, and an image processor with a calculation circuit for extraction of characteristics and two two-dimensional frame memories at least. One is the memory for recording the characteristic value such as the maximum brightness in each pixel. The other is for recording another measured value such as the displacement of the object table when the pixel point has the characteristic value.

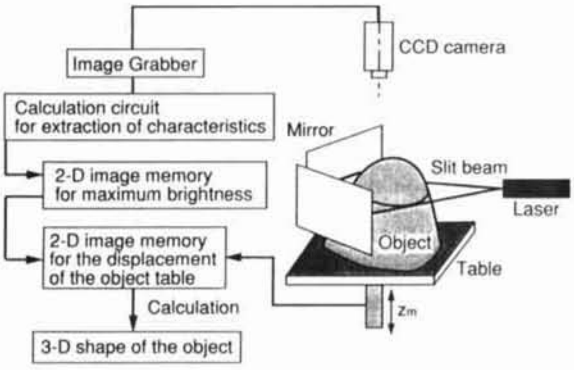


Fig.1 Setup and flow chart for the shape analysis

In this method, The image of the contour line is digitized on an image processor. The brightness of the image is compared with the memory of the characteristics in each pixel. If the brightness of the obtained image is larger than the one on the first memory for the characteristic value, the brightness of the obtained image is newly recorded in the memory of the characteristic value and another measured value i.e. the displacement of the object table is recorded in the same pixel point on the second memory. These operations are repeated in all pixel points of the image. After this process, the current image obtained by a camera is discarded.

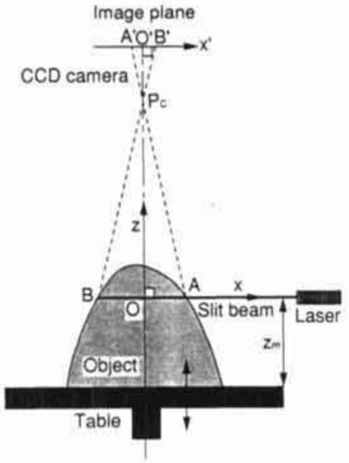


Fig.2 Setup for convex shape measurement

Changing the condition such as the displacement of the table, the operations described above are repeated. After moving the table from the top of the object to the bottom, the characteristics and another measured value are recorded in the two two-dimensional memories. The profile of the object can be calculated from the second memory. As a result using this method, the requisite data can be extracted from the three-dimensional image composed of a large number of two-dimensional images without large memory space and long processing time.

3 PRINCIPLE OF SHAPE MEASUREMENT

3.1 CONVEX SHAPE MEASUREMENT

In order to perform noncontact shape measurement for convex objects, an automated measurement system illustrated in Fig.1 is developed. The process to obtain the characteristics and the displacement of the object table is described in Sec.2. The spatial coordinates of the object are obtained from the memory for the displacement of the object table using the following equations.

$$x_A = r x_A' \tag{1}$$
$$y_A = r y_A' \tag{2}$$
$$z_A = -z_m \tag{3}$$

where, r is the reciprocal of the magnification factor in image plane. x_A' and y_A' are the coordinates of the point A projected by the beam on the image plane. z_m is the displacement of the table.

The profile of the full surface of the object can be described by calculating the above equations for all pixel points.

3.2 CYLINDRICAL SHAPE MEASUREMENT

It is impossible to measure the shape of cylindrical objects with concave along z axis using the method described in Sec.3.1. A new method is proposed for such cylindrical shapes. The setup is shown in Fig.3. The top view of the setup is shown in Fig.4. It requires two frame memories as well as in the convex shape measurement.

A vertical thin slit beam light is projected onto the surface of the object on a turning table. The axis of the turning table is in the plane of the beam light if the object is removed. The deformed thin light is recorded by a CCD camera whose optical axis is horizontal and crosses the beam at a certain angle θ.

For measuring the full surface of the object, the images of the slit beam on the object are recorded at every constant angle while the turning table is rotated. In this case, however, the possibility that the beam positions at different rotating angles are on the same pixel point is high as shown in Fig.5(a)~(d). Only one datum on the same pixel point is valid and the other data are discarded. In order to avoid the many superpositions on the same point, the images are shifted horizontally in proportion to the rotating angle shown in Fig.5(e)~(h). The first memory has the maximum brightness in each pixel, and the second one memorizes the rotating angle of the table when the pixel point has the maximum brightness.

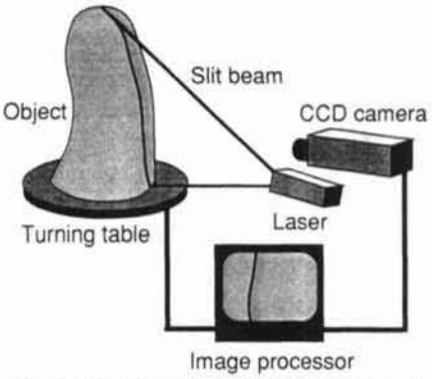


Fig.3 Setup for cylindrical shape measurement

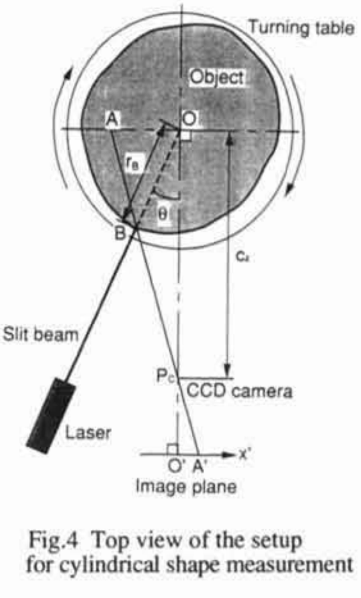
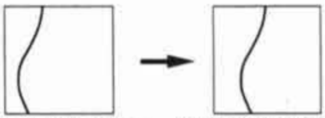
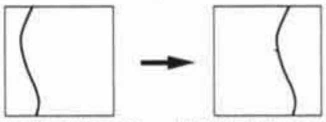


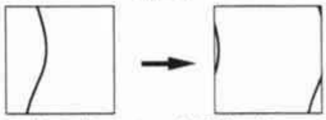
Fig.4 Top view of the setup for cylindrical shape measurement



(a) Image of beam line in ϕ_{m1} (e) Shifted image of (a)



(b) Image of beam line in ϕ_{m2} (f) Shifted image of (b)



(c) Image of beam line in ϕ_{m3} (g) Shifted image of (c)

(d) Superposed image of (a)(b)(c) (h) Superposed image of(e)(f)(g)

Fig.5 Process for shifting images

These operations are repeated until the images of the beam over the full surface are recorded. The rotating angle pitch or the pixel size of the image is adjusted so that the total shifted pixel number is coincide with the horizontal pixel number of the image after rotating 360° . As considered from Fig.4, the spatial coordinates of the point B projected by the beam is calculated by the position A' of the point projected by the beam on the image plane using the following equations.

$$r_B=rx_A'c_z/(c_z\sin\theta+rx_A'\cos\theta) \tag{4}$$

$$z_B=(1-r_B/c_z)ry_A' \tag{5}$$

$$\phi_B=\phi_m \tag{6}$$

where, r_B is the radius of the point B. z_B is the vertical position of the point B. x_A' and y_A' are the x-directional and the y-directional distances from the origin O' on the image plane to the point A' respectively. ϕ_B is the angle of the point B. ϕ_m is the angle recorded in the memory of the rotating angle of the table.

The profile of the full surface of the object can be described by repeating the calculations of Eqs.(4)~(6) for all pixel points.

4 APPLICATIONS

Two examples of applications based on the above methods are presented. One is the measurement of the shape of a hemisphere. The other is the measurement of the shape of an above-knee socket.

4.1 SHAPE MEASUREMENT FOR A HEMISPHERE

A hemisphere is put on the object table shown in Fig.2. A horizontal thin slit beam emitted from a laser is projected onto the surface of the object. The contour line is viewed by a CCD camera. By moving the table at every 0.20mm, the image is obtained and operated described in Sec. 3.1. One of the images of the contour line of the specimen is shown in Fig.6. The result of the shape measurement is shown in Fig.7.

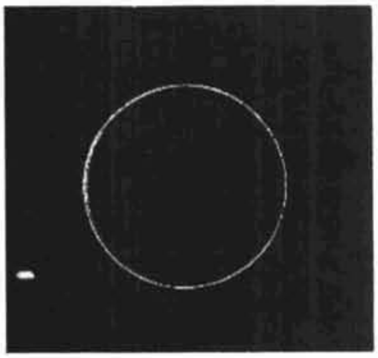


Fig.6 An image of the contour line of the object (z_m=10.0mm)

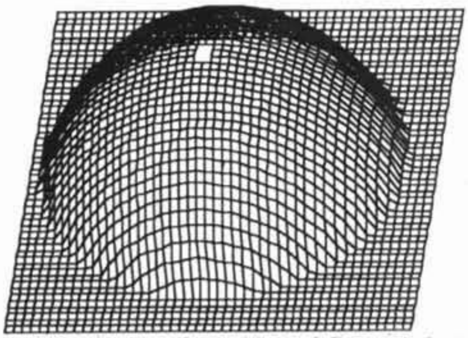


Fig.7 Measured shape of the object (3-D expression)

4.2 SHAPE MEASUREMENT FOR AN ABOVE-KNEE SOCKET

An above-knee socket for an amputee is put on the turning table shown in Fig.3. A vertical thin slit beam light emitted from a laser is projected onto the surface of the socket. The line is viewed by a CCD camera. By rotating the turning table at every 1 degree, the image is obtained and operated as described in Sec 3.2. Each image obtained by changing the angle of the turning table is shifted rightward horizontally by a pixel every 2 degrees correspondingly. One of the images of the thin beam projected onto the specimen is shown in Fig.8. The image of the rotating angle of the turning table is shown in Fig.9. The size of the image analyzed is 180 x 240 (pixel). The result of the shape measurement is shown as a cross-sectional shape in Fig.10. The direction of the shift of the images is the right.

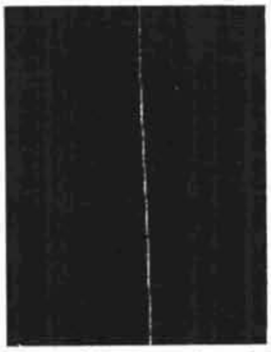


Fig.8 An image of the beam line of the object (ϕ_m=120 degree)

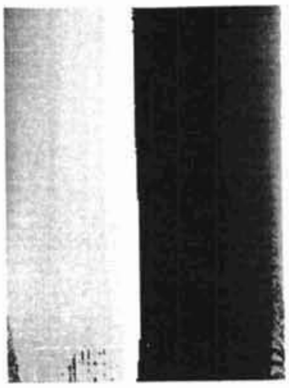


Fig.9 Image of the rotating angle of the turning table

Fig.10 Cross-sectional shape of the object (rightward shift, at z=0mm)

As shown in Fig.10, There are an area where the information about the shape are sparse. It is caused by the coincidence of the movement of the beam line on the image plane and the movement by shifting the image. As a result, the points projected by the beam on the image plane accumulate on the same point again and again.

To obtain the shape information uniformly, the images shifted leftward are obtained, and the maximum brightness in each pixel point are recorded respectively. The result of the shape measurement with shifting the images leftward is shown as a cross-sectional shape in Fig.11. After the calculations of the shape, these results obtained by shifting rightward and leftward are superposed. The result combined two results is shown in Fig.12. It shows a uniform data density distribution. Like this, the shape of the cylindrical object is easily obtained.

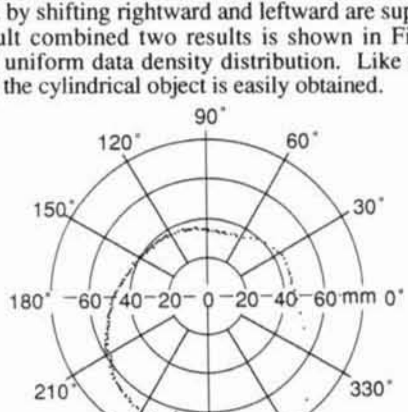


Fig.11 Cross-sectional shape of the object (leftward shift, at z=0mm)

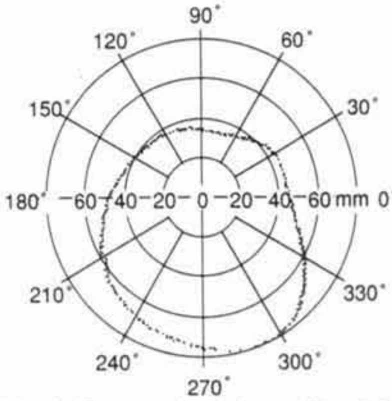


Fig.12 Cross-sectional shape of the object (combined Fig.10 with Fig.11)

5 CONCLUSIONS

A new image processing method by extraction of characteristics is proposed. Two measurement systems are developed for convex shapes and cylindrical shapes. Using this method, high speed and accurate shape measurement are performed. In the system for cylindrical shapes, the shape of cylindrical object can be obtained accurately and uniformly by shifting images rightward and leftward and analyzing respectively.

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