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Autonomous Measurement of Physical Model Shape for Reverse Engineering

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Abstract

This paper describes a system to autonomously measure the shape of an unknown physical object for constructing the computer model of a physical object. The system is composed of two subsystems: one is for the rough recognition of a physical object and the other is for the precise measurement. A physical object is roughly recognized as the *Z*-map model that is constructed by analyzing and processing the shadow images of an object obtained by CCD cameras. The precise measurement of discrete points on the object is autonomously made according to the *Z*-map model using a three-coordinate measuring machine.

Keywords: *Reverse Engineering, Autonomous Measurement, CAD, Rough Model, Three-Coordinate Measuring Machine*

Introduction

In the design of the exterior of automobiles, household appliances, cellular phones, and so on, curved surfaces are used widely to enhance design features and functionality. One problem faced in the use of a CAD system for the modeling of these curved shapes is the difficulty involved in achieving the design aims. Designers are able to easily express their design concepts by physical models, such as clay and wooden models of the exterior shape, when designing product shapes, but there is a need for technology to convert physical models to CAD models (computer models). One such technology is called reverse engineering,[1-4] which is based on the technique of measuring the shape of physical models and applying a data processing technique for constructing CAD models from the measured data.

In shape measurement for reverse engineering in the designing process, autonomous measurement is difficult because the shape of the object to be measured is unrecognizable. The shape and features are therefore usually measured manually by experienced operators. To realize the automatic and autonomous measurement of physical models using a three-coordinate measuring machine (CMM), there is a need to autonomously determine the position and direction of approach by the measuring probe and the coordinates of the targeted points to be measured, which in turn creates the need for recognition of the overall shape of the physical model. At the same time, the position and orientation of the model (workpiece) on the CMM table must also be clear.

This study aims to develop an automatic and autonomous measuring method of model shapes in reverse engineering for aesthetic design—in other words, to develop automatic and autonomous measurement of models whose shapes are not identified. This measurement can be realized in the two steps: rough recognition of the model and precision measurement. This paper describes a system that obtains projected images of a physical model using CCD cameras from various directions and roughly recognizes the shape, position, and orientation of the physical model as the *Z*-map model from the image information obtained. Also reported is a system that autonomously constructs a measuring strategy based on the *Z*-map model and automatically measures the physical model by autonomously building the CMM part program.

Construction of *Z*-Map Model

Acquisition of Projected Images of Physical Model

As shown in *Figure 1*, the physical model (workpiece) is placed at any position and orientation on the turntable fixed on a CMM table. The rotational axis of the turntable is taken as the Z axis, while the axis that passes through the rotational axis of the turntable and is vertical to the rotational axis is taken as the R_i axis. Two CCD cameras, R and Z, are set up so that the optical axes of the cameras match the two axes, R_i and Z, respectively.

The rotation angle of the turntable is initially set to the reference position (home), and the physical

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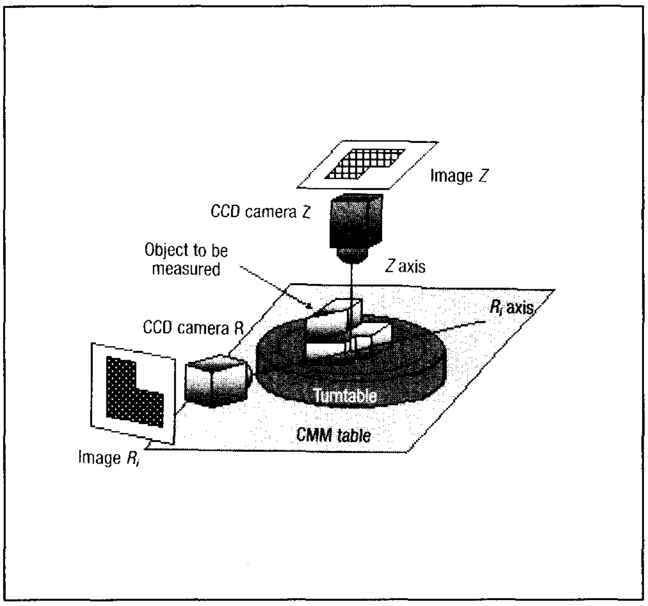

Figure 1
Acquisition of Images of an Object

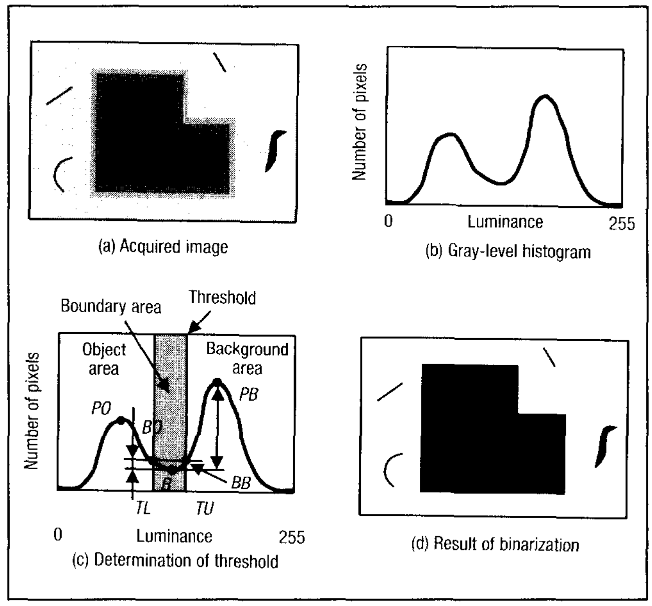

Figure 2
Determination of Threshold for Binarization

model is exposed using the two CCD cameras. At this time, the optical axis of camera R is taken as the axis R_0. Next, the turntable is rotated only for the angle of n degrees, and the model is exposed by camera R. In this case, the optical axis of camera R is taken to be the axis R_n. The exposure by camera R is repeated as many times as necessary, and the angle of the turntable is set as desired to 0, 90, 45, and 135 degrees. When exposing the model, setting many R_i axes will enhance the accuracy of the *Z*-map model constructed.

Image Processing

Binarization is carried out as the blob process to identify the images of the physical model, after which the physical model exposed images are generated. To facilitate this process, the background is made bright to increase the contrast between the physical model image and background image. Even with a large contrast, the boundary of the physical model image and background is sometimes not clear, or the binarized values of the background may not be consistent at certain parts according to image noise and electric noise. For this problem, the binarization threshold for the image is determined using the following method.

The images obtained by the CCD camera are obtained as information on the optical intensity of the image combined on the CCD pixel-elements. The CCD camera used in this study has a resolution of 485 pixels horizontally and 570 pixels vertically. The image information is arranged two-dimensionally in the form of 480 pixels horizontally and 512 pixels vertically and is obtained as the light-intensity value at the respective points (0 to 255 luminance value). A histogram of the light intensity and pixel number is compiled. Like the images (*Figure 2a*) obtained in this study, if the luminance of the physical model image (workpiece measured) is relatively small and that of the background is large by contrast, the histogram becomes a twin-peak pattern as shown in *Figure 2b*. In *Figure 2c*, the population distribution with the peak of the smaller luminance (peak value *PO*) represents the physical model image, while that of the larger luminance (peak value *PB*) represents the background image. The valley part of the mountains (distribution between the luminances *TL* and *TU*) represents the boundary between the physical model image and the background image. The luminance value *B* of the bottom-most point at the valley of the histogram can be taken as the threshold value for differentiating the physical model images and other images in binarization. However, the aim of constructing the *Z*-map model from the image data is thus to provide information for building measuring strategies for precision measurement using a CMM, as well as to clarify the physical model shape for determining the measuring path and targeted points to be measured where no interference between the physical model and the