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Evaluation of 3D shape measurements under water condition

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Abstract
Until now, many three-dimensional (3D) shape measurement methods have been proposed by several researchers. However, most of the 3D shape measurement systems measure only in air. In recent years, 3D shape measurement systems have had a wide industrial application for engineering in various environments. Thus, 3D shape measurement systems are required in various conditions such as in gas, liquid and vacuum. Therefore, it is important to develop a 3D shape measurement system which can measure the object in medium of various refractive indexes.
In this study, a 3D shape measurement system by an optical projection method had been developed. The reconstruction equations from 2D image at known refraction condition have been proposed. In this paper, the improved 3D shape measurement system by an optical line projection method is proposed. The condition of the refraction between air and water is selected to evaluate the proposed 3D measurement system. Effects of several parameters, which are optical path length in air and water, and camera resolution, are evaluated at experimentally. The experimental results showed that the 3D shape can be reconstructed correctly. The modified transformation equation using the Snell's law for various refractive indexes is effectively improved the accuracy of 3D shape measurement. The average error for each direction is less than 0.10mm and the standard deviation for each direction is less than 0.20mm at present conditions.

Keywords: 3D shape measurement, refraction, under water measurement

1. Introduction

Until now, many three-dimensional (3D) shape measurement methods have been proposed by several researchers [1, 2]. However, most of the 3D shape measurement systems measure only in air. Thus, a 3D shape measurement system is required in various conditions such as in gas, liquid and vacuum. Examples of application of the 3D shape measurement are a work piece measurement in reactive gas and liquid for micro- and nanoprocess, a wear measurement of object in oil and a precise automatic control of a robot arm in space. Therefore, it is important to develop the 3D shape measurement system which can measure the object in medium of various refractive indexes.

In this study, the 3D shape measurement system by an optical projection method has been developed [3]. The reconstruction equations from 2D image at known refraction condition have been proposed. The experimental results showed that the 3D shape can be reconstructed correctly. However, effects of the system condition were not properly evaluated. Therefore, the system accuracies were not enough for the precise shape measurement.

In this paper, effects of several parameters, which are optical path length in air and water, and a camera resolution, are evaluated at experimentally using the proposed 3D shape measurement system.

2. Measurement system

A photograph of the proposed 3D shape measurement system is shown in Fig. 1. The system consists of a semiconductor laser as a light source, a cylindrical lens, a rotating mirror and a CCD camera. A beam which has a line pattern intensity distribution from the semiconductor laser with lens is projected on a surface of an object of measurement. The line beam is deformed due to the surface profile. The deformed reflection beam is captured by the camera. The incident angle of the beam is defined by the rotating mirror which is controlled by the computer. The position of the camera is set perpendicular to the line pattern direction. The mirror, the object and the camera form an optical triangulation system. Therefore, the 3D information of the surface of the object is obtained from the 2D captured image using transformation equation. The object is located in a water tank. The tank is made of glass and is filled with water.

In this case, the incident and the reflected beams travel through three mediums which is air, glass and water. Thus, the beam is refracted at each boundary. Therefore, modified transformation equation is applied using Snell's law for various

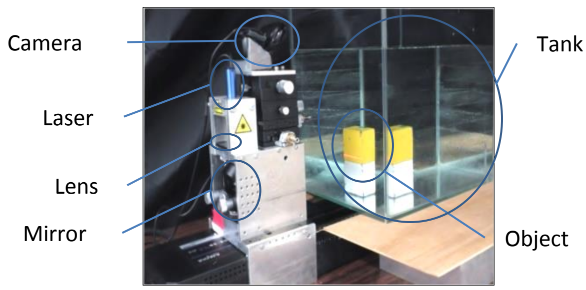

Figure 1. Photograph of the 3D shape measurement system.

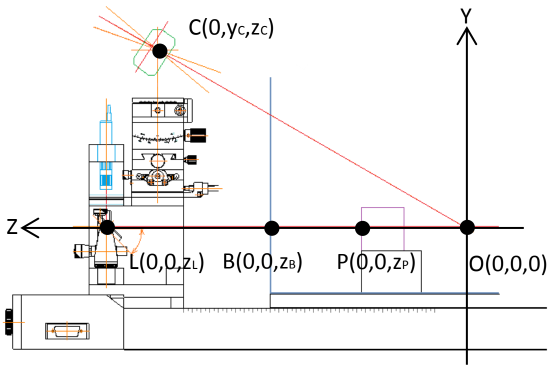

Figure 2. Schematics of the 3D shape measurement system.

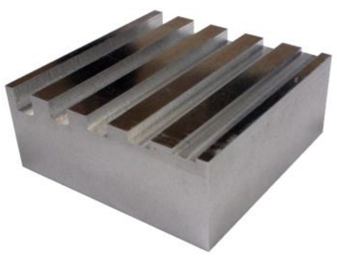

Figure 3. Photograph of the sample object.

refractive indexes. The laser with the line pattern is used to obtain a high optical intensity. The overall dimensions of the developed system are 110mm (width), 153mm (depth) and 295mm (height). The system is easy to carry around and can be applied to various machines.

3. Results and discussion

Fig. 2 shows the schematics of the 3D shape measurement system in the YZ plane. The basic experimental conditions are 640pixel ×480pixel camera, z_L = 260mm, z_B = 80mm, z_P = 0mm, y_C = 175mm and z_C = 200mm. The number of measurements is five times for each condition. The measurement area is 225mm in the X direction and 180mm in the Y direction on the XY plane.

Dimensions of the object are 50.5mm × 50.5mm ×20.0mm, as shown in Fig.3. There are 5 trenches from 1mm to 5mm deep and 3mm wide. This is made of aluminium.

Fig. 4 shows the measurement error as a function of the boundary position. The average measurement error slightly decreases with increasing the boundary position, because of the changing of the beam pass.

Fig. 5 shows the average measurement error as a function of the camera position. The average measurement error increases with increasing the camera position.

Fig. 6 shows the average measurement error as a function of number of pixels of the camera. The average measurement error is decreased with increasing the number of pixels. In Fig.6, lines are spatial resolution curves for each direction on the camera. Most of the average measurement errors are under the resolution.

From these results, the effect of boundary condition is not observed clearly. The average measurement error for each direction is less than 0.10mm and the standard deviation for each direction is less than 0.20mm at present conditions. The main effect of the measurement error is an actual camera resolution. The results are also indicated that the modified transformation equation using the Snell's law for various refractive indexes is effectively improved the accuracy of 3D measurement.

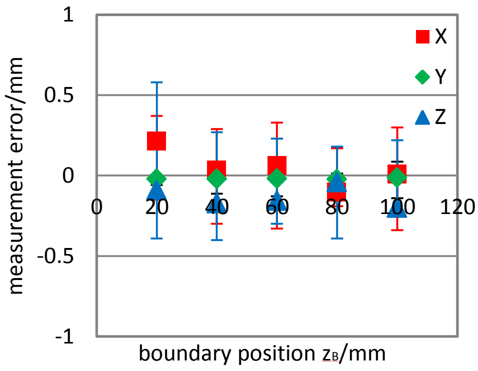

Figure 4. Effect of the boundary position.

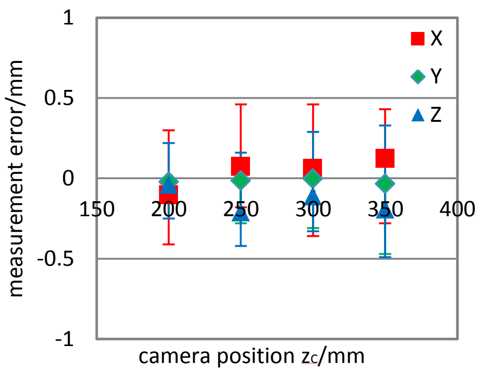

Figure 5. Effect of the camera position.

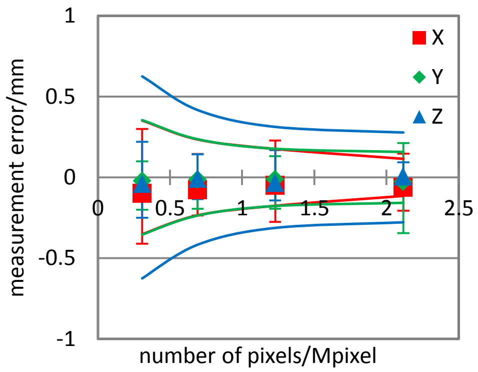

Figure 6. Effect of the camera resolution.

4. Concluding remarks

In this paper, effects of several parameters, the optical path length in air and water, and the camera resolution, are evaluated experimentally using the proposed 3D shape measurement system. The condition of the refraction between air and water is selected to evaluate the proposed 3D measurement system.

From the results, the effect of boundary condition is not observed clearly. Therefore, the modified transformation equation using the Snell's law for various refractive indexes has effectively improved the accuracy of 3D shape measurement. The average measurement error for each direction is less than 0.10mm and the standard deviation for each direction is less than 0.20mm at present conditions. In future work, the system in the various refractive conditions will be evaluated.

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