3D shape measurement under multiple refraction condition using optical projection method

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Abstract

We propose the improved 3D shape measurement system under multiple refraction condition using optical projection method. This system consists of a laser, a camera and a computer. This system using the optical projection method is a system that projects a line pattern from the laser to the object surface, captures the object surface image by the camera, processes the acquired image information with the computer by the principle of the triangulation, and records and shows the shape of the object surface on the display. New image analysis method is performed using Matlab for calibration, calculation and display. We evaluated this system in air and water conditions, experimentally. Results show that the 3D shape can be reconstructed correctly. Experimental results also indicated that the average errors for X, Y and Z are 0.05, 0.02 and 0.04 mm in both conditions, respectively.

1 Introduction

Three-dimensional (3D) shape measurement system has many applications such as anthropometry in medical field and product inspection in industry. Therefore, many measurement methods have been proposed by several researchers [1, 2]. However, most of them measure only in air. In recent years, the 3D shape measurement system has a wide industrial application for engineering from the micro-nano precision measurement to the wide area measurement. Thus, the 3D shape measurement system is needed in various conditions such as in gas, liquid and vacuum. Examples of application of 3D shape measurement are work piece measurement in reactive gas and liquid for micro-nano process, wear measurement of object in oil and precise automatic control of 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. Until now, 3D shape measurement systems in water using ultrasonic have been proposed by researchers. These measurement systems can detect only for wide measurement range.

We had developed the 3D shape measurement system and experimental results showed that the 3D shape can be reconstructed correctly [3]. However, the system accuracies are not enough for the precise shape measurement. In this paper, we propose the improved 3D shape measurement system under multiple refraction condition using an optical line projection method and investigate this system in detail. New calibration and image analysis method is also proposed.

2 Measurement Principle

The schematic diagram of the 3D shape measurement system is shown in Fig.1. The system consists of a semiconductor laser, a rotating mirror, a camera, a computer and a display. A line pattern from the laser is projected on a surface of an object. The incidence angle(α) is defined by the rotating mirror angle. The deformed pattern is captured by the camera, which is set perpendicular to the line pattern direction. The object, the laser with the mirror, and the camera form an optical triangulation system. Therefore, the 3D physical spatial coordinates can converted from the 2D camera image coordinates. The object is located in the various refractive indexes such as air and water. In this case, the incident and reflect light beams travel through two or more mediums. Thus, transformation equation is applied using Snell's law for various refractive indexes. And we selected the line pattern projection method to obtain a high optical intensity.

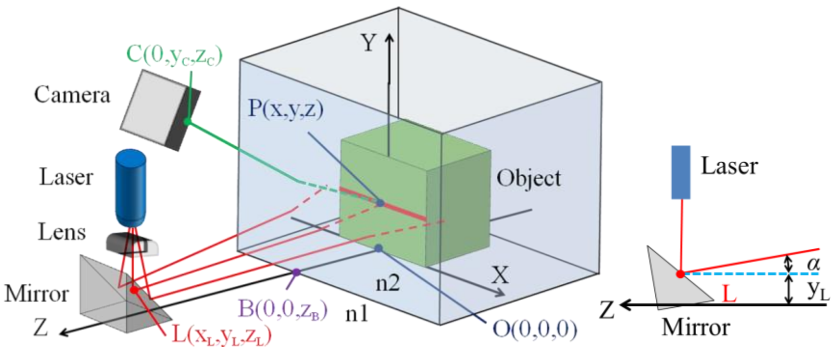

Figure 1: Schematic of measurement system

3 Measurement Procedure

Flowchart of the measurement system is shown in Fig.2. The measurement procedure starts from the setting of the system including camera calibration. Parameters which are the laser position, initial incidence angle, camera position, camera angle and boundary are determined. However, there are various error causes such as the laser position error, the incidence angle error, the camera position error, the camera angle error, the distortion of lens aberration, etc. The known reference 50 points are pre-measured to calibrate the system. 2nd step is projection processing of the pattern and capture processing of the pattern on the surface of the object. We used difference image to improve an accuracy of the image processing using background image. 3rd step is image data processing. Erosion and dilation are used to image denoising. To detect maximum brightness for direction of perpendicular to the line pattern, Gaussian distribution function approximation is used. Therefore, sub-pixel accuracy for Y direction can be expected. 4th step is coordinate transformation from 2D to 3D using transformation equation. To measure the whole object 3D data, we repeat the step 2-4. And final step is storage and display of 3D measurement data of the object surface. The measurement process is performed using Matlab.

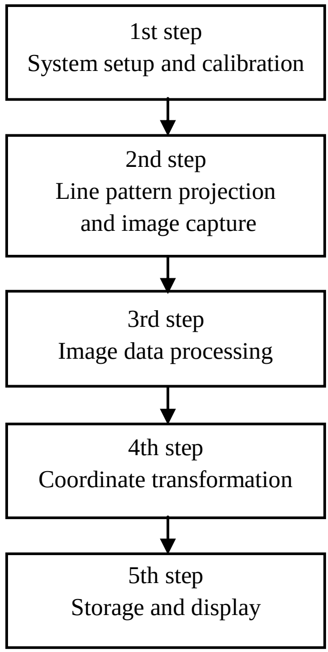

Figure 2: Flowchart of measurement system

4 Results and Discussion

In present system, basic experimental conditions are 1280 x 960pixel camera, C(0,175,200), L(0,0,260), B(0,0,80), P(0,25,0)(object center) and n_1=1.000 (in air). Measurement area is X=225mm and Y=180mm at Z=0mm. Calculated resolution of the camera for X, Y and Z are 0.18, 0.18 and 0.31mm, respectively. A sample object is 50.5x50.5x20mm with 1-5mm trench, 1-5mm depth and white. To evaluate the effect of the refractive index, n_2=1.00 and 1.33 (in water, uniform condition) at 20°C are selected. Number of measurements is 5. Figure 3 shows the measurement error as a function of the true value for X, Y and Z axes. Experimental results indicated that the average errors for X, Y and Z are 0.05, 0.02 and 0.04mm in both conditions, respectively. Results also indicated that the standard deviations for X, Y and Z are 0.10, 0.07 and 0.09mm in air and 0.14, 0.07 and 0.09mm in water, respectively. These values are under resolution of camera in present system. However, some results have errors larger than camera resolution due to the edge effect of the captured image.

5 Concluding Remarks

In this paper, we propose the improved 3D shape measurement system under multiple refraction condition using optical line projection method. Image analysis is performed using Matlab for calibration, image analysis, calculation and display in short time.

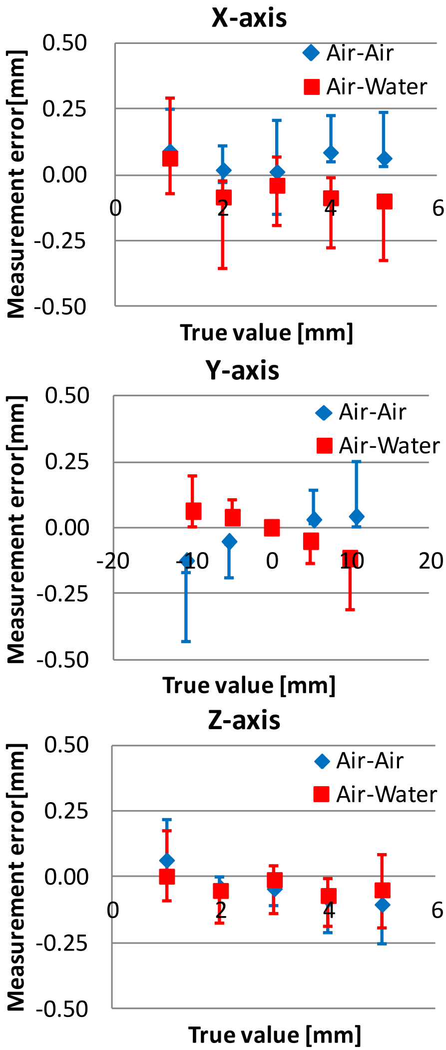

Figure 3: Measurement error for X, Y, Z

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