Image Measurements of Three-dimensional Shapes of Solid Objects and Liquid Free Surfaces

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ABSTRACT

This paper presents a novel image measurement technique to measure three-dimensional shapes of solid objects and liquid free-surfaces. In this technique, three-dimensional locations of the surface, where color grids are illuminated by a PC projector, can be estimated from recorded digital images of the grids reflected on the surface. This imaging technique was found to be capable of measuring the three-dimensional coordinates of solid surfaces at high accuracy with mean error less than 0.1 mm through experimental tests. Complex shapes of a breakwater composed of armor block models and of water wave surfaces have been reasonably measured in this technique.

KEY WORDS: imaging measurement; solid shape; surface shape;

INTRODUCTION

Under violent waves, serious damages of coastal structures, such as dispersions of armor blocks and partial failures of breakwater, have been reported. In such case, prompt measurements and specification of the damaged locations and deformed shapes of the structures are expected for repairing or reconstructing the structures to recover functions of the structures. A final goal of this study is to establish new technique to easily measure three-dimensional shapes of any structures for detecting deformations of the structures and also quantitatively evaluating dimensions of the constructed structures. As a fundamental research, in this paper, the measurement accuracies for the proposing technique are estimated to examine reliability of the technique through laboratory tests.

In the proposing method, the object surface, where color grids are illuminated by a PC projector, is recorded by a digital camera in a similar experimental setup to Chen and Li, (2003). The three-dimensional object shapes can be estimated on the basis of the recorded relative locations of the projecting grids on the surface. This technique is applied to the shape measurements of laboratory models of armor block units and breakwaters for finding applicability to block stability tests of the coastal structures.

Another possible application of this technique is to measure a planar distribution of water surface level in laboratory wave experiments. Since the surface level has been normally estimated using one point measurements such as wave gages and pressure sensors, many experimental instruments need to be arrayed to obtain the instantaneous planar surface level in a complex wave field involving reflected and diffracted waves around the structures. The image measurement of wave surface shapes is also performed for finding uncertainties expected in the laboratory wave experiments.

MEASUREMENT ALGORITHM

In the present method, a PC projector and digital video camera are used for measuring the three-dimensional shape of an object (see Fig. 1). A square grid pattern (see Fig. 2) is projected from the PC projector to illuminate the object. The object surface, where the grid pattern is reflected, is recorded by the camera. The real coordinate is related to the image coordinate on the basis of a conventional pin-hole model as shown in Fig.1. Assuming a perspective transformation with the center $O_c$, the image coordinate on the focal plane can be given by

$$ x_c = f_c \frac{X_c}{Z_c} \quad (1) $$

$$ y_c = f_c \frac{Y_c}{Z_c} \quad (2) $$

where $(X_c, Y_c, Z_c)$ is the local real coordinate, in which the origin is located at $O_c$ and $Z_c$ has an identical orientation with the optical axis, and $f_c$ is the focal length of the camera (distance between the focal plane and $O_c$). When the unit vectors $i_c = (i_{cx}, i_{cy}, i_{cz})$ and $j_c = (j_{cx}, j_{cy}, j_{cz})$, which are perpendicular to $k_c$, on the focal plane are defined, the image coordinate

$$ O_c N_c = \frac{f_c}{O_c M_c \cdot k_c} O_c M_c \quad (3) $$

Here $k_c = (k_{cx}, k_{cy}, k_{cz})$ is the unit vector in the optical axis the camera.