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MEASUREMENT OF SPATIAL-TEMPORAL WAVES IN THE LABORATORY USING COMPUTER VISION TECHNOLOGY

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1 INTRODUCTION

Given the complexity of ocean wave phenomena, physical modeling continues to be essential in various engineering and research applications. Wave height, a characteristic measured in nearly all projects, is commonly assessed using resistance/capacitance wave gauges. However, a significant limitation of these traditional wave gauges is their point-based nature, which restricts their ability to describe detailed spatial wave characteristics, especially during wave nonlinearity or when waveforms change. Furthermore, to reconstruct the 3D wave field, an array of wave gauges is often employed alongside an appropriate interpolation algorithm. Additionally, wave gauges may alter flow/wave conditions in specific scenarios. To address these limitations, various non-intrusive measurement techniques have been proposed. Gomit *et al.* (2022) classified these into stereoscopic, projection, and light-based methods, including LiDAR (Blenkinsopp *et al.*, 2012), RGB-D cameras (Martínez-Aranda *et al.*, 2018), and binocular stereo vision (Li *et al.*, 2022). However, their applicability is constrained by factors such as optical setup complexity and device cost. With the rapid advancement of computer vision technology, it is possible to improve these issues and better describe temporal and spatial wave field variations using such techniques. This conference contribution details the reconstruction of the temporal and spatial 3D free water surface using photogrammetry techniques applied to images from consumer webcams. It also compares these results with measurements obtained from a wave gauge.

2 METHODS

Photogrammetry techniques, which reconstruct depth information from 2D images, were utilized, and the open-source photogrammetric computer vision framework “AliceVision” (Griwodz *et al.*, 2021) was applied in this work. The 3D free water surface reconstruction primarily relied on the structure from motion (SfM) and multi-view stereo (MVS) techniques. SfM estimates the 3D structures and camera poses (positions and orientations) from a sequence of 2D images through detected features, typically using the scale-invariant feature transform (SIFT) algorithm. MVS uses the information from SfM to generate depth maps for each camera and creates a dense geometric surface by merging all depth maps. During the reconstruction process, the coordinate information of CCTag markers, consisting of concentric circles (Calvet *et al.*, 2016), is specified to provide local coordinate references and quantify the generated 3D free water surface. The AliceVision framework comprises several photogrammetry pipelines, including feature extraction, image matching, feature matching, structure from motion, depth map estimation, meshing, texturing, localization, and more.

Experiments on wave focusing during wave propagation, induced by a submerged crescent shoal modified from previous work (Weng *et al.*, 2013), were conducted in the flume at the Center of Ocean Engineering Experimental Research (COEER), National Taiwan Ocean University. Figure 1 illustrates the basic setup of the experiments. The entire wave propagation process was captured by six AVerMedia consumer webcams, model PW310P (indicated by red dots in Figure 1), which targeted the area of interest. This area, where glass microspheres (ϕ=100-180 μm and ρ=0.1-0.6 g/cm^3) were dispersed for enhanced image recognition, is shaded in Figure 1. In addition to an incident wave gauge, a capacitance wave gauge was positioned in the area of interest to record water level variations simultaneously. Before initiating the experiments, it was necessary to establish a local coordinate reference system using CCTag markers to provide a quantitative basis for the 3D water surface reconstruction process.

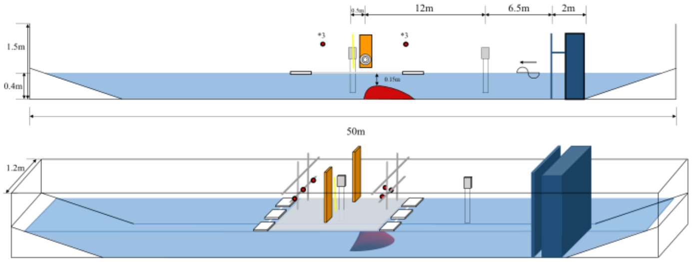

Figure 1. Schematic setup of the experiment.

Prior to the 3D water surface reconstruction, data preprocessing, including video synchronization, was performed to ensure high-quality image data. This involved using both sound and light signals for video synchronization. The end product of the 3D water surface reconstruction is a point cloud, which can undergo further post-processing if deemed necessary. This point cloud enables the reconstruction of the water surface and the extraction of pertinent information. These processes are designed to be automated to minimize unnecessary complications, although manual intervention is possible. Figure 2 (a) depicts the reconstructed water surface, highlighting the wave focus as regular waves traverse a submerged shoal, while Figure 2 (b) presents the water level time series at a point behind the shoal. This is measured by the wave gauge and derived from the 3D free water surface reconstruction. The incident wave height is recorded at 5.56 cm, the wave gauge measures the wave height at 6.24 cm, and the wave height extracted from the 3D free water surface reconstruction is 6.28 cm.

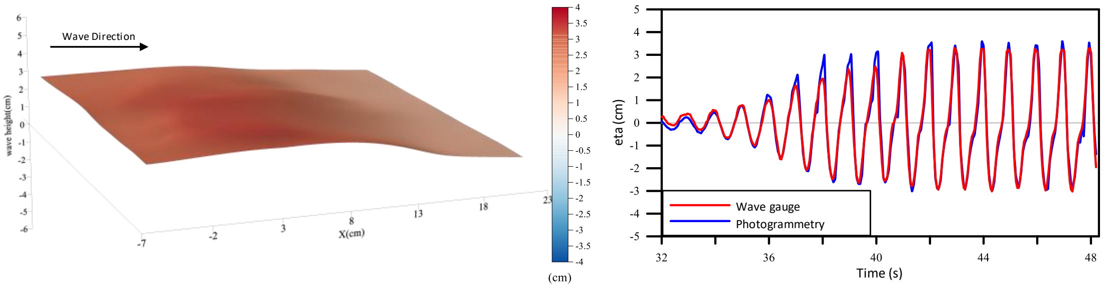

Figure 2. Results of wave focusing: (a) Reconstruction of the 3D free water surface, (b) Comparison of water levels measured from a wave gauge and extracted from the 3D free water surface reconstruction.

3 CONCLUSIONS

This conference contribution introduces and validates a laboratory-scale measurement method employing computer vision techniques. This method effectively reconstructs water surface variations using data from webcam recordings. It captures wave characteristics at a single location, akin to traditional wave gauges, and can also reconstruct the 3D free water surface, revealing wave fields over time and space. With appropriate temporal and spatial resolution, it is possible to capture more detailed variations in the wave field. This approach provides an effective supplementary tool for measuring wave characteristics, offering advantages over traditional wave gauges.

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