Chapter 6
Deformation Measurement of Structure Using Sampling Moire Method with SfM-MVS

Shohei Itakura and Motoharu Fujigaki

Abstract SfM-MVS (Structure-from-Motion/Multi-View Stereo) is user-friendly and capable of producing high-quality 3D models without the need for specialized equipment. These advantages are particularly beneficial in the field of measurement. In this study, we proposed a method for deformation measurement of structures using the sampling moire method combined with SfM-MVS. We conducted an experiment using a rubber square beam with a 2D-grating pattern. During the experiment, a weight was placed on the rubber square beam, and 3D models were created both before and after deformation. The displacement distributions obtained using this method were then compared with the value obtained by laser displacement meter. It was confirmed that obstacles were removed through editing, allowing for effective deformation measurement.

Keywords SfM-MVS · Sampling moire method · Displacement measurement · Deformation measurement

Introduction

Recent years, infrastructures such as bridges and tunnels built during the period of high economic growth have been getting dilapidated. They must undergo inspections and maintenance to ensure their longer safety. One of the way to inspect them, Sampling moire method has been proposed and the displacement distributions are obtained using a camera and a 2D-grating [1]. The method has been applied to measure several railroad bridges for high-speed railway. However, in actual sites, there may be cases where obstacles are present in front of the target or where front-facing images cannot be captured due to the target being at a high elevation. Therefore, this study proposes a method for measuring the deformation of target objects by applying the sampling moiré method in a virtual space based on a 3D model created using SfM-MVS. This method enables us to measure objects in that environment because of editing of a 3D model. Using images generated from the 3D model, the feasibility of performing measurements using this method is experimentally investigated.

Proposed Method

SfM-MVS is a technique that generates 3D models from multiple images taken of a target object. This technology is used in various fields such as architecture, civil engineering, and disaster sites, and research on its application in measurement is actively being conducted [2, 3]. The sampling moiré method measures minute displacements by analyzing moiré fringes obtained through image processing of images capturing grid patterns before and after deformation. The proposed method applies the sampling moiré method to obtain displacement distributions by generating images with matching camera positions for the 3D models reconstructed before and after deformation using SfM-MVS. As shown in Figure 1, obstacles can be removed through editing, enabling the generation of images that would otherwise be impossible to capture in reality. At this time, it is essential that the 3D models before and after deformation are placed at the same coordinates in the virtual space, for example, by setting appropriate reference points. Any misalignment in position would appear as displacement in the measurement results; hence, precise alignment is required.

Shohei Itakura · Motoharu Fujigaki
Department of Human and Artificial Intelligent Systems, Graduate School of Engineering, University of Fukui, Bunkyo 3-9-1, Fukui, 910-8507
e-mail: fujigaki@u-fukui.ac.jp

Chi-Hung Hwang et al. (eds.), *Advancement of Optical Methods & Digital Image Correlation in Experimental Mechanics, Vol. 2*, Conference Proceedings
of the Society for Experimental Mechanics Series, https://doi.org/10.13052/97887-438-0828-2_6

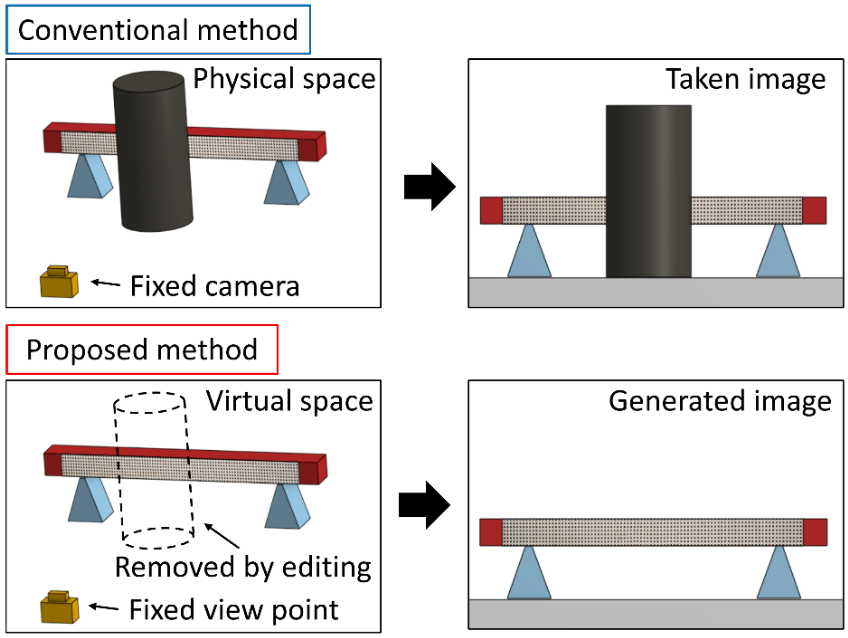

Fig. 1 Conventional method and Proposed method

Experiment

The material used for deformation is a rubber rectangular prism (30 × 60 × 500 mm, hereafter referred to as the beam). A 2D grating with a 4 mm pitch, used for the sampling moiré method, is attached to the side surface of the beam. As shown in Figure 2, an obstacle (PVC pipe) is placed in front of the beam, and a laser displacement meter is positioned so that its pointer hits the center of the object from below.

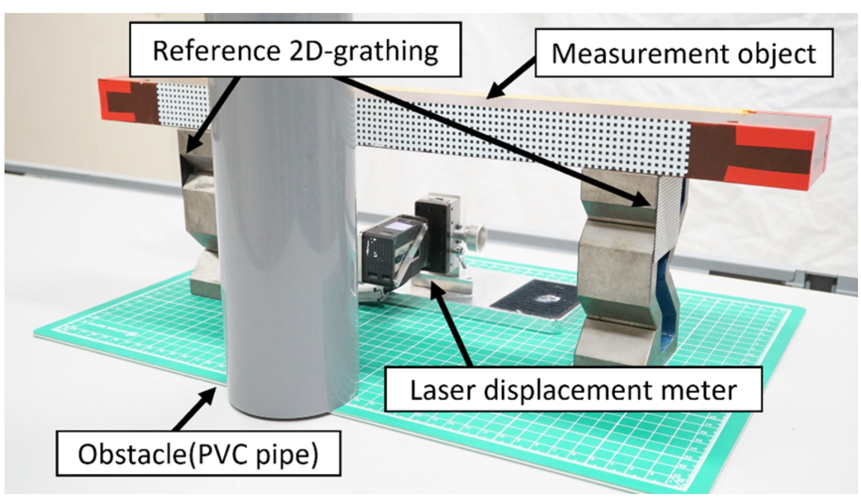

Fig. 2 Experimental environment

3D models of the object are created before and after deformation by placing a weight on the beam. After removing the obstacle from the models through editing, images generated from the same viewpoint are analyzed using the sampling moiré method to measure displacement. Simultaneously, the displacement at the center of the object is measured using the laser displacement meter.

Equipment and Software

The 3D models are created using *iTwin Capture Modeler Master* by Bentley Systems. For visualization, the free software *CloudCompare* is used. *iTwin Capture Modeler* allows users to set the coordinates of any point from the images captured during the 3D modeling process. Additionally, the scale of the models can be adjusted by selecting two points and setting the length of the line segment between them. *CloudCompare* enables the editing of 3D models, fixing viewpoints, and displaying multiple 3D datasets simultaneously within the same coordinate system. The displacement distribution obtained by the sampling moiré method is analyzed using *Fukuface*, a general-purpose image analysis software developed in our laboratory. A *SONY* α*7S* camera was used, capturing approximately 150 images before and after deformation.

3D Model Alignment

The alignment of the 3D models was performed using the feature for setting reference points from the captured images. As shown in Figure 2, reference grids were placed at both ends of the support structure. The fine patterns of the grid facilitate accurate plotting of reference points, and the precisely determined pitch aids in scale adjustment. As shown in Figure 3, the origin was set on the reference grid, and three additional points were designated as references for the axes and scaling.

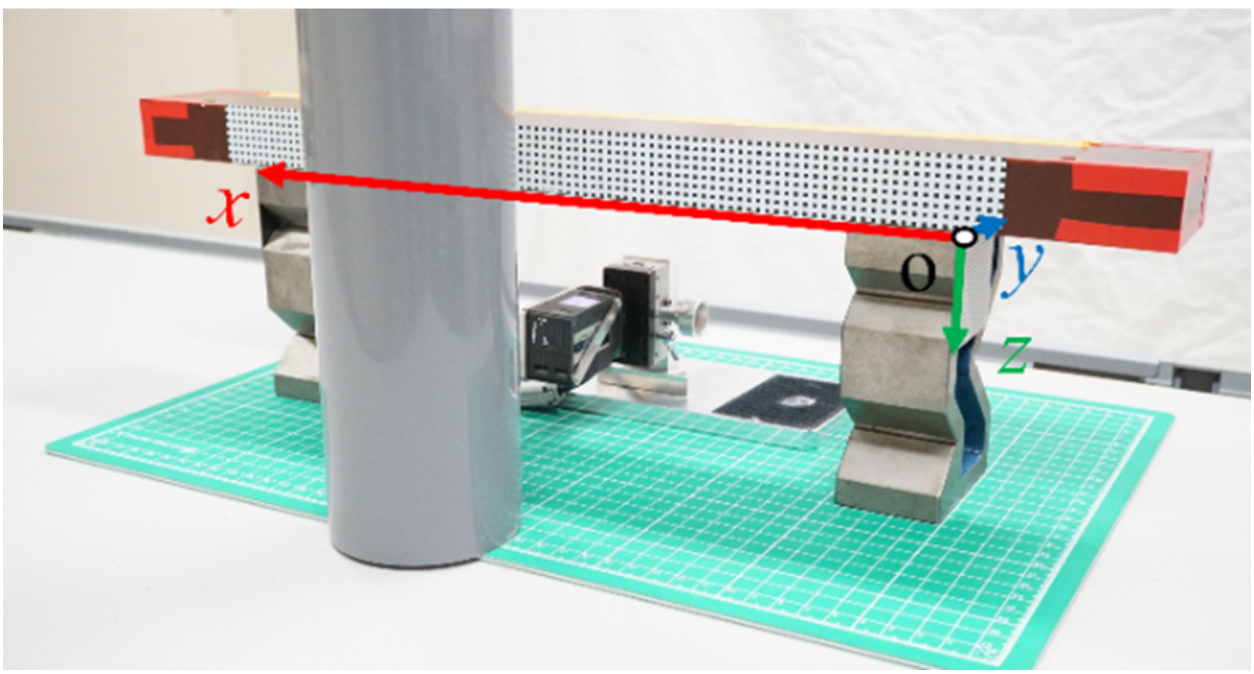

Fig. 3 Origin and axis arrangement

Displacement Analysis Results

Figure 4 and 5 show images generated from the 3D models before and after deformation, respectively. The obstacle in front of the target object was removed through editing, and front-facing images of the grid were generated.

Figure 6 (a) and 6 (b) present the displacement distributions in the x and y directions, respectively, obtained by applying the sampling moire method to the edited images in Figure 4 and 5.

The x-direction displacement shows a distribution where both ends appear to lift, while the y-direction displacement shows a distribution where the central portion sinks significantly. These distributions align with the expected displacement patterns when a weight is placed at the center of the object.

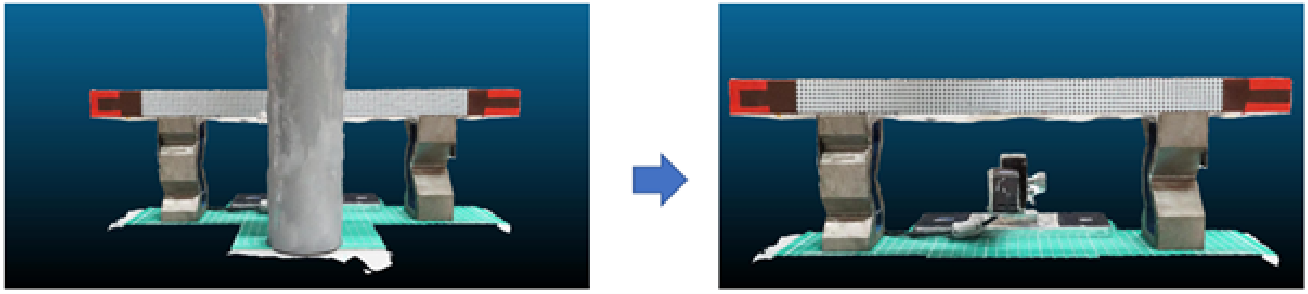

Fig. 4 Images generated from the 3D model before deformation (Left: Before editing, Right: After editing)

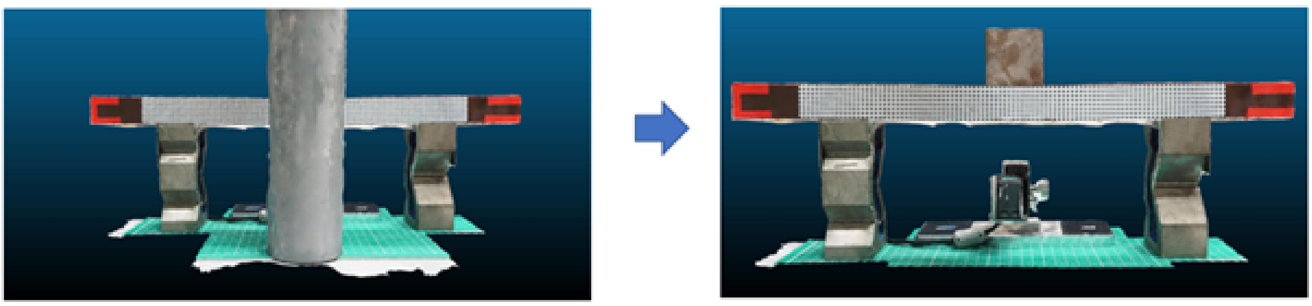

Fig. 5 Images generated from the 3D model after deformation (Left: Before editing, Right: After editing)

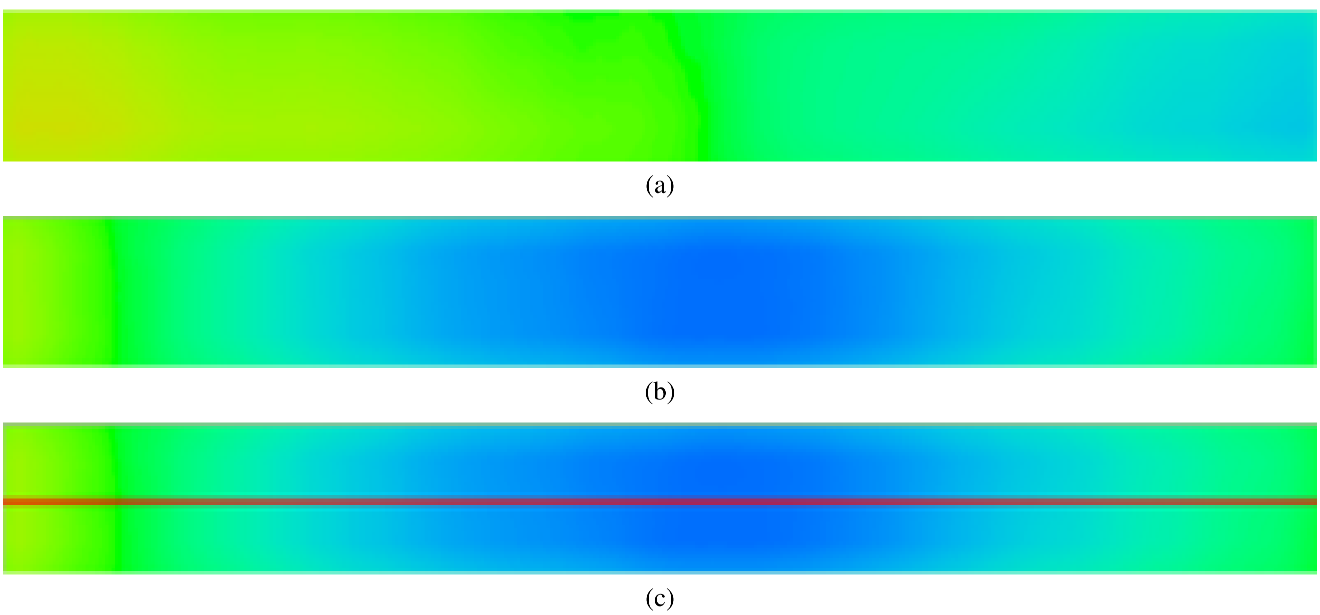

Fig. 6 Displacement Distributions (a) Displacement in the x-direction (b) Displacement in the y-direction (c) Cross-sectional view

Figure 7 shows a graph representing the cross-sectional data along the red line in Figure 6 (c). The displacement at the center of the object is measured as −1.013 mm. The corresponding measurement by the laser displacement meter at the same location is −0.961 mm, resulting in a difference of 0.05 mm.

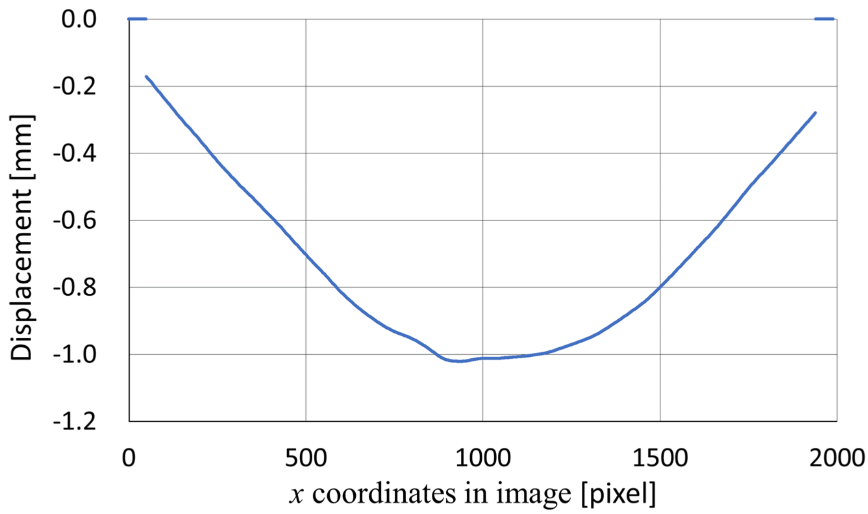

Fig. 7 Cross-sectional Analysis

Conclusion

This paper proposes a method for measuring the deformation of an object by applying the sampling moiré method in a virtual space based on 3D models created using the SfM-MVS technique. The feasibility of this measurement approach was experimentally verified. The proposed approach, which involves generating 3D models before and after deformation in a virtual space and using them to measure displacement distributions, was introduced in this study. To further validate this method, future experiments will be conducted with an expanded range of measurement targets. Ultimately, the goal is to apply this technique to the inspection of infrastructure using drones.

References

1. Ri, S., Fujigaki, M. and Morimoto, Y. "Sampling Moire Method for Accurate Small Deformation Distribution Measurement" *Experimental Mechanics*, April 2010
2. Fuse, T. "Structure from Motion (SfM) Part 2: SfM and Multi-View Stereo" *Photogrammetry and Remote Sensing*, 2016
3. Kanai, S., Date, H., and Tanaka, M. "Generation of 3D Models of Infrastructure Structures Based on Measurements and Their Application to Maintenance and Management" *Measurement and Control*, November 2021