Measurement of Full-Field 3D Displacement of Large Structures using a Multi-camera stereo-DIC System

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Abstract. In large-scale applications, the use of a single stereo pair is inherently constrained by limited spatial coverage, perspective distortion, and loss of feature correspondences. These challenges can result in incomplete or unreliable measurement of full-field displacements. To address these issues, this study introduces a multi-camera stereovision-based framework designed for full-field 3D displacement measurement and mode shape reconstruction. The developed framework utilizes a Full-Field Feature-Based Clustering (FFFBC) approach with a novel target-independent camera calibration method. One of the major challenges in large-scale optical measurement is camera calibration. Standard calibration methods, such as checkerboard-based techniques, require controlled setups and known geometric patterns. For large structures, placing calibration targets within the field of view is often impractical. To overcome this, a novel target-independent calibration method has been developed, leveraging scene features and geometric constraints to estimate camera parameters. The framework is tested on a retired aircraft structure, which is manually excited to capture its displacement response in 3D and determine the modal characteristics. The results demonstrate the effectiveness and robustness of the developed multi-camera stereo-DIC approach in studying the structural dynamic behavior of large aerospace structures.

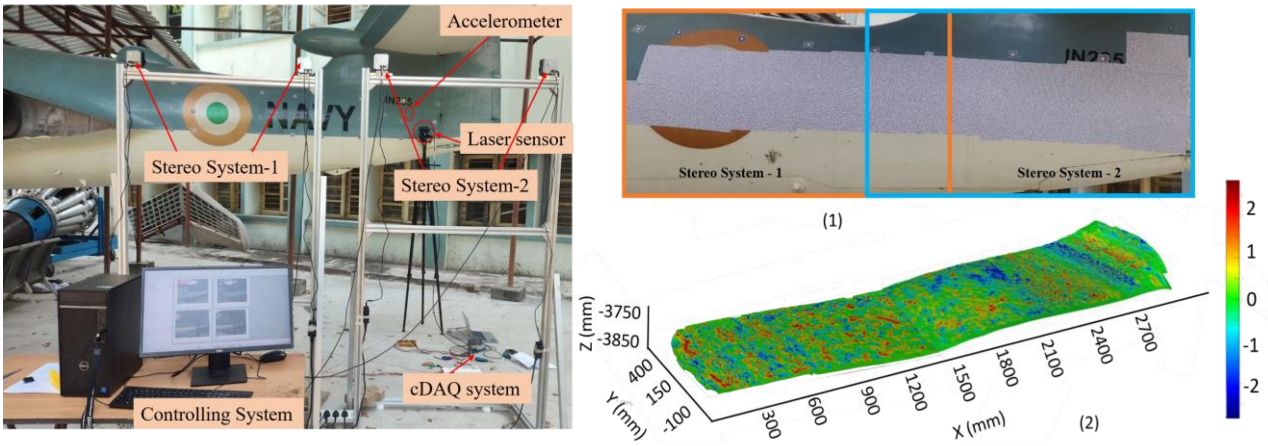
Introduction

Vision-based methods have been widely explored in measuring full-field 3D displacements of large structures using stereovision camera systems. However, one stereovision system is often considered to be inadequate for large structures due to its limited field of view (FOV), perspective constraints, and insufficient feature coverage. These issues result in incomplete displacement fields and decreased measurement accuracy. In order to resolve this issue, various studies have attempted integrating multiple stereovision systems together to capture full surface-level profile of the large structures. A multi-camera system provides a practical solution by extending the observable area through overlapping views, improving feature visibility, and enabling consistent tracking across large spatial domains [2, 4]. Here, each stereo pair independently produces separate full-field 3D displacement contours corresponding to its field of view. Integrating these individual measurements into a unified global full-field displacement representation remains a significant challenge, particularly in large-scale applications. To address this, a simple strategy is to place them side by side [5]. The present work proposes a multi-camera stereovision-based framework combined with a Full-Field Feature-Based Clustering (FFFBC) approach [3] and a target-independent camera calibration technique [1] to achieve reliable full-field 3D displacements and mode shapes of large structures.

Methodology and Preliminary Results

The proposed methodology is an incremental advancement of the previously developed Full-field Feature-based Clustering (FFFBC) algorithm and a target-independent calibration method. These elements are integrated with a multi-camera system to measure the full-field displacement of large structures. The experimental setup consists of two stereo camera systems, utilizing four Basler boost boA2448-250cc cameras equipped with 8mm Basler lenses. This setup covers a field of view (FOV) of 3 meters horizontally and 1.5 meters vertically. In this work, we conducted experiments on a retired Hawker Sea Hawk IN-235 aircraft, which is manually excited to capture full-field displacements (as shown in Fig. 1(a)). In order to validate the results, a laser displacement sensor (ME optoNCDT 1700) is mounted on a tripod and a piezoelectric accelerometer is installed on the target surface (see Fig 1(a)). The FFFBC algorithm detects uniformly distributed feature-based clusters in the reference image and regenerates missing features in subsequent frames to maintain correspondence. The cluster centroids identified in sequential images are then matched both temporally and across the stereo image pairs to establish motion and spatial correspondences. A target-independent camera calibration method was adopted to estimate the geometric relationship between image and world coordinates without using conventional calibration targets. The approach utilizes natural or artificially pasted features within the scene, which are detected in paired images using the KAZE feature detector.

A known physical distance between selected feature points is used to establish pixel-to-metric conversion in the image plane, enabling computation of corresponding 2D image coordinates and metric X and Y values. The relative depth(Z) information of feature points is obtained using a distance-measuring laser sensor from a reference location. By combining the 2D pixel coordinates with their corresponding 3D world coordinates, a calibration dataset is formed. A custom MATLAB script is then used to estimate camera parameters, where an initial guess and baseline are provided, and triangulation is performed. The parameters are further refined using non-linear optimization based on the Levenberg-Marquardt (LM) algorithm, ensuring accurate mapping between image space and object space for reliable 3D reconstruction [1].



(a) (b)

Figure 1: (a) Experimental setup with two stereo systems and (b) Speckled region for Full-field 3D displacements (1. Separate ROIs for two stereo systems and 2. W displacement (mm) global contour).

Finally, stereo triangulation is used to reconstruct 3D surface mesh, and their temporal variations are applied to compute the full-field displacement across the entire structure. After independently reconstructing the full-field 3D shape from each stereo camera pair, we achieve the resulting global full-field 3D shape through the mathematical stitching process. After achieving global stitching (see Fig. 1(b)) through a mathematical transformation model, we successfully reconstructed a unified full-field 3D displacement of the entire region of interest (refer to Fig. 1(b)). This displacement ranged from -2.5 mm to +2.5 mm, representing the structure as a single continuous domain. The integrated displacement field provided clear visualization of the global structural response, with the first mode shape of the aircraft structure (the ROI selected of 3 m) effectively. Thus, depicting a coherent deformation pattern.

Conclusion

This study presented multi-camera stereovision-based framework that employs a target-independent camera calibration technique. It measures full-field 3D displacement and reconstructs mode shapes of large structures using a Full-Field Feature-Based Clustering (FFFBC) approach. By utilizing multiple cameras, the framework extends the field of view, improves feature tracking, and ensures precise reconstruction of spatial displacement over large structural areas. The results highlight the significance of multi-camera systems in overcoming limitations of conventional vision-based techniques, offering a scalable and feasible solution for full-field analysis of large structures.

References

[1] Jangam Babu, Sneha Prasad, and David Kumara. *A target-independent sensors-based stereo camera calibration technique enabling 3d-dic for large structures.*

[2] Jinke Huang and Xinxing Shao. *Multi-camera stereo-digital image correlation: A review*. Advanced Devices & Instrumentation, 7:0127, 2026.

[3] Sneha Prasad, David Kumar, Yung-Chiang Lin, Chih-Hung Chiang, Mahesh Mahesh, and Wei-Long Chen. *Ai-dic drone system for real-time 3d vibration testing of large structures*. In Nondestructive Characterization and Monitoring of Advanced Materials, Aerospace, Civil Infrastructure, and Transportation XX, volume 13950, pages 64–72. SPIE, 2026.

[4] A Sabato, P Poozesh, P Avitabile, and C Niezrecki. *Experimental modal analysis of a utility-scale wind turbine blade using a multi-camera approach.* In Journal of Physics: Conference Series, volume 1149, page 012005. IOP Publishing, 2018.

[5] Xulong Xi, Yan Liu, Pu Xue, Xiaochuan Liu, Chunyu Bai, Xinyue Zhang, and Liqiang Gao. *High-speed multi-camera videogrammetric measurement of full-field 3d motion and deformation in full-scale crash testing of typical civil aircraft*. Aerospace Science and Technology, 152:109375, 2024.