Chapter 7
3D Motion Detection Using Computer Vision During Earthquakes

Andrés Garreaud, Ruben Boroschek, and Domingo Mery

Abstract In recent years, the field of Computer Vision has gained significant traction in civil engineering, largely due to advancements in techniques and the increased availability of data from cameras and unmanned aerial vehicles (UAVs). This work presents a series of controlled experiments in which objects are recorded on video while following predefined motion patterns on a six-degree-of-freedom shake table. The dimensions of the objects are fully known, allowing a single camera to be used for tracking. This case is important because understanding the benefits and limitations of single-camera video during seismic events is highly relevant. Handheld cameras and surveillance systems inside buildings generally lack binocular (stereo) vision. The motion patterns range from simple movements to complex ones derived from actual seismic recordings, and the amplitudes vary from low-level ambient vibrations to severe earthquake motions. Using Computer Vision techniques, motion is first estimated in 2D space through feature tracking across video frames, then transformed into 3D space using a calibrated camera model. Calibration is performed using the known object dimensions. We assess the accuracy of the proposed approach by comparing the estimated displacements with the predefined motion patterns. The limitations of the method are identified and discussed. These results contribute to the development of more robust and precise Computer Vision workflows, which can be applied to more complex environments, such as real-world seismic structural monitoring.

Keywords Displacement estimation · 3D motion detection · single-camera tracking · computer vision · seismic monitoring

Introduction

Over the past few years, computer vision techniques have become increasingly common for monitoring and inspecting structures [1, 2, 3]. Among the most relevant applications is the estimation of structural displacements, traditionally addressed through 2D methods such as homography or the scale factor approach [4, 5]. These techniques, however, are limited to planar motion. More complex challenges arise when estimating 3D displacements, typically requiring two or more cameras for triangulation [6].

In contrast, estimating 3D motion with a single camera is far more challenging due to the lack of stereoscopic information. Recent studies have explored neural networks [7], segmentation [8, 9], and calibration models to address this issue [10]. Building on this line, the present work proposes a method that combines monocular vision with optimization techniques, integrating prior knowledge of object geometry to estimate 3D displacements. The method is experimentally validated using a six-degree-of-freedom shake table, where a rigid object with known dimensions is subjected to predefined motion patterns and recorded with fixed cameras. AprilTags were included in the setup but were not used for this extended Abstract.

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The proposed method begins with the detection and tracking of features on the studied object. Several detection algorithms were evaluated (FAST [11], SURF [12], and Harris Corner [13]); the Harris detector was selected in this case. Feature tracking across frames was then performed using the KLT algorithm [14], yielding the 2D trajectories of all points. The relationship between a 3D point with coordinates (X, Y, Z) and its 2D projection was implemented using a novel methodology that optimally finds the intrinsic and extrinsic parameters for this case. This methodology is presented in [15].

Laboratory Validation

A six-degree-of-freedom shaker table is employed to conduct a series of experiments aimed at verifying and validating the proposed method. A black solid box and two 3D-printed cubes were placed on the table, and all objects were rigidly fixed to ensure that they moved together, strictly following the imposed motion patterns. The equipment is shown in Figure 1, while their arrangement is depicted in Figure 2.

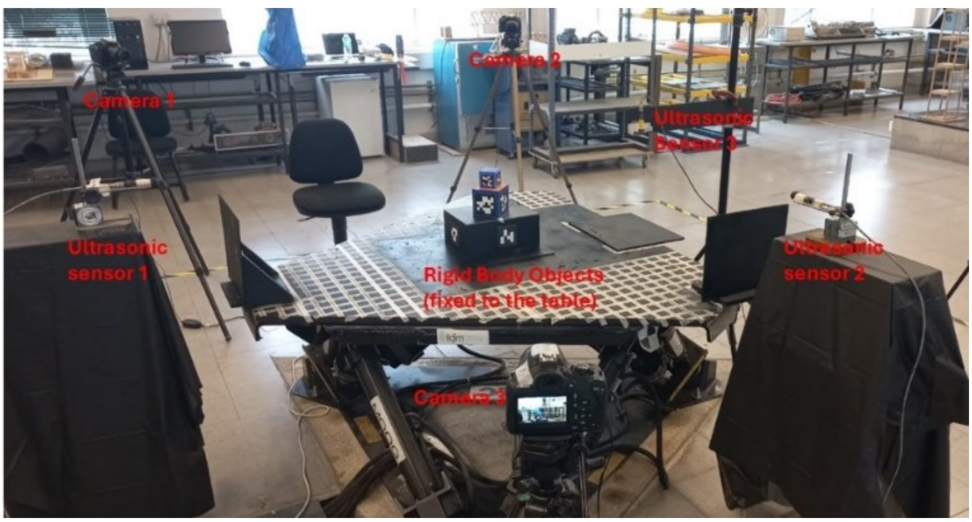

Fig. 1 Laboratory experimental setup

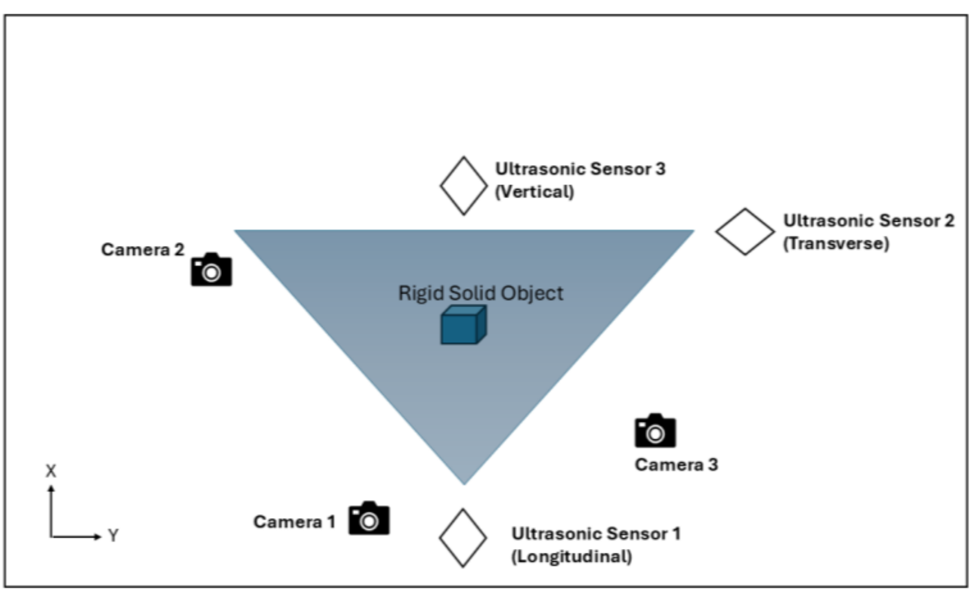

Fig. 2 Schematic representation of the experimental setup

Three Canon Rebel T6 cameras were mounted on tripods to record different faces of the object, operating at 1920×1080p and 30 fps with manual settings. One camera at a time was used to test the methodology. Table motion was independently measured using three ultrasonic sensors (BANNER S18U, 200 Hz), one per axis. Regarding the motion patterns, two records were employed. The first was manually generated and consisted of three displacement pulses in the principal directions (X, Y, and Z), each lasting 5 seconds with a maximum amplitude of 5 cm. Similar results were obtain from the different tests. The second record corresponds to seismic data from the 2010 Chile earthquake. Only the results for the earthquake-induced 3D motions are presented.

Results

For the 2010 Chile Earthquake Constitución record, features were independently tracked by Cameras 1–3. The estimated displacements (Figures 3–5) closely follow the sensor data, reproducing both strong-motion peaks and slower phases with high accuracy. Cameras 1 and 2 show excellent agreement in all directions, while Camera 3 provides precise results in X and Z but underestimates amplitudes along Y during the strong-motion phase. Quantitative results (Table 1) indicate RMSE values below 1 cm (≈1% error), with maximum deviations of 2.06% and 3.69% in the X and Y directions of Camera 3, respectively. All CCF values remain above 0.95, confirming the reliability of the method.

Table 1 Displacement measurement errors for seismic recording test

		Camera1			Camera 2			Camera3	
	X	Y	Z	X	Y	Z	X	Y	Z
RMSE (cm)	0.09	0.19	0.11	0.13	0.15	0.07	0.23	0.65	0.05
NRMSE (%)	0.9	1.1	1.9	1.2	0.87	1.3	2.06	3.69	0.92
CCF (-)	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.95	0.99

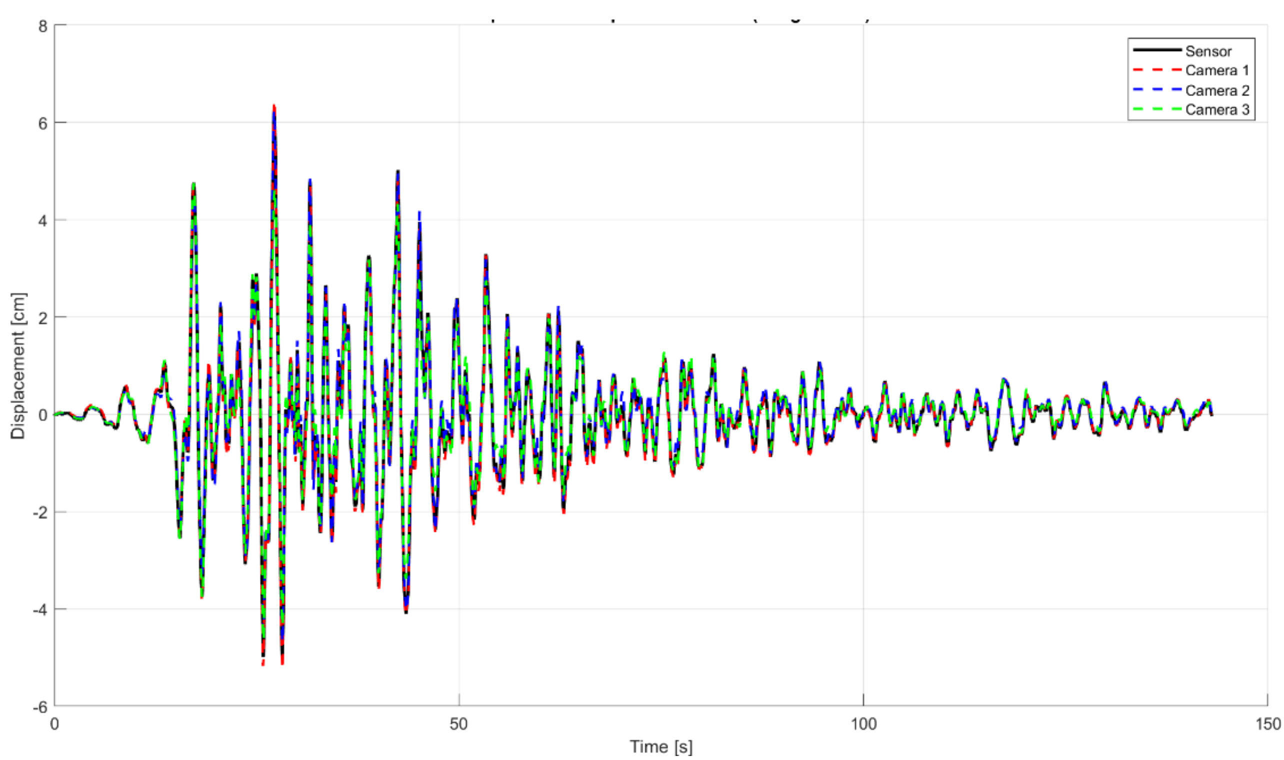

Fig. 3 Comparison of displacement results along the X direction

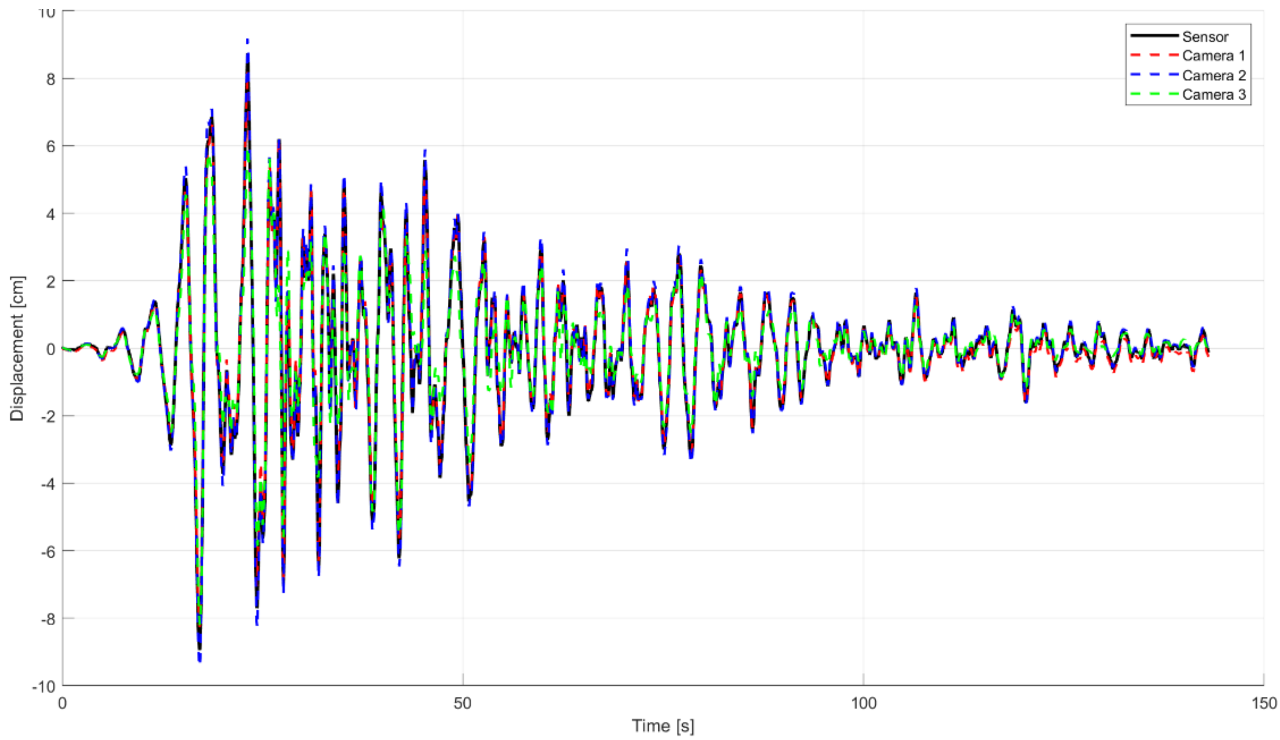

Fig. 4 Comparison of displacement results along the Y direction

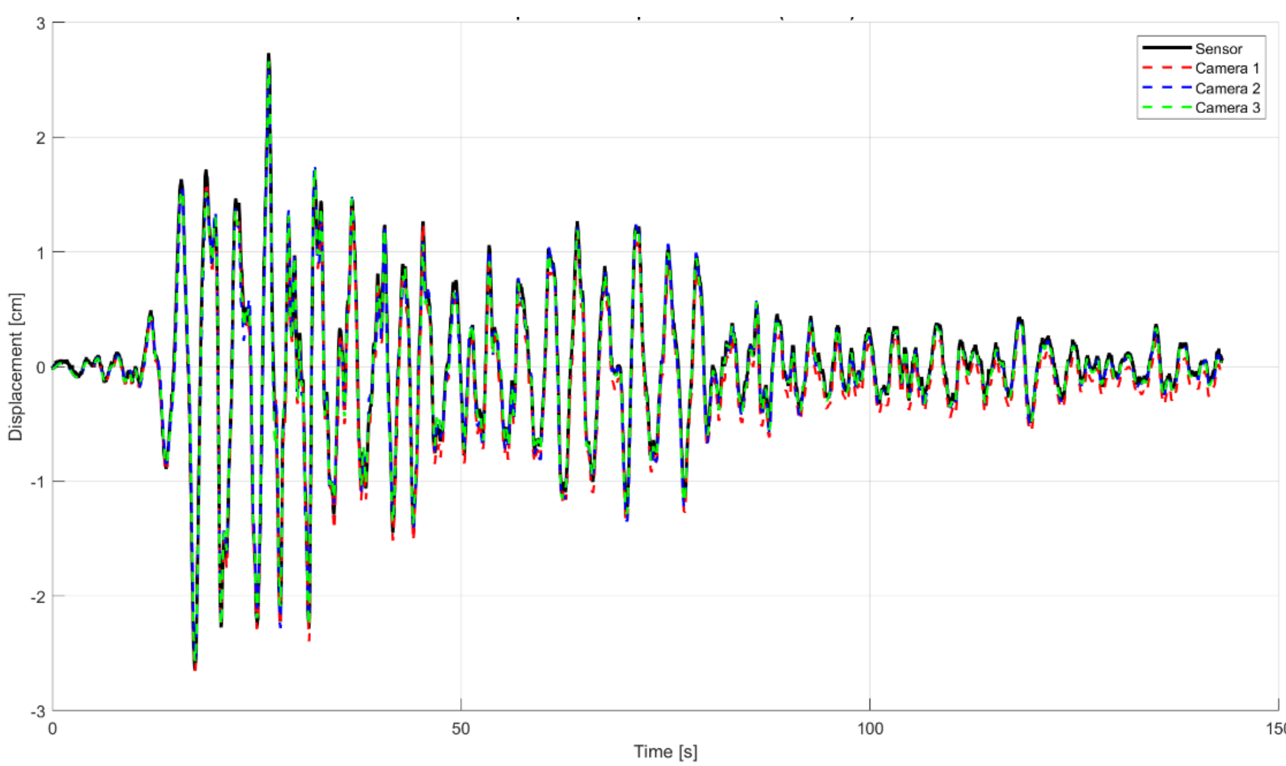

Fig. 5 Comparison of displacement results along the Z direction

Conclusion

This study demonstrates that single cameras can be effectively used to track known objects during severe earthquakes with high accuracy. The proposed method, based on monocular vision and optimization techniques, successfully reproduces 3D displacements consistent with sensor measurements, even under strong-motion conditions. We are applying this method to real videos during earthquakes, and the results will be presented in a forthcoming working paper.

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