INSTITUTE OF FUNDAMENTAL TECHNOLOGICAL RESEARCH
AND COMMITTEE ON MECHANICS
POLISH ACADEMY OF SCIENCES

7th European Conference on Structural Control

Book of Abstracts and Selected Papers

Editors:

Jan Holnicki-Szulc, David Wagg and Łukasz Jankowski

Co-editors:

Bartłomiej Błachowski and Piotr Tauzowski

WARSAW 2022

INSTITUTE OF FUNDAMENTAL TECHNOLOGICAL RESEARCH
AND COMMITTEE ON MECHANICS
POLISH ACADEMY OF SCIENCES

7th European Conference on Structural Control

Book of Abstracts and Selected Papers

Editors:
Jan Holnicki-Szulc
David Wagg
Łukasz Jankowski

Co-editors:
Bartłomiej Błachowski
Piotr Tauzowski

WARSZAWA 2022

Comparison of the accuracy of computer vision-based methods for estimation of structural displacements using synthetic video data

Mariusz Ostrowski[1], Bartlomiej Blachowski[1], Mateusz Zarski[2,3], Bartosz Wojcik[2,3], Piotr Tauzowski[1], and Lukasz Jankowski[1]

[1]*Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw, Poland*
[2]*Silesian University of Technology, Gliwice, Poland*
[3]*Institute of Theoretical and Applied Informatics, Polish Academy of Sciences, Gliwice, Poland*

e-mail: mostr@ippt.pan.pl

1. Introduction

Despite significant advances in structural health monitoring (SHM), the design of contact sensor networks and their power supply for large-scale structures is still expensive and difficult [2]. Due to the recent progress in computer vision (CV) it is possible to monitor structural components or even whole structures with the aid of digital cameras that allow to avoid the use of the contact sensors [4]. However, CV-based measurements have a significantly lower accuracy than the techniques based on the contact sensors. Moreover, the amount of benchmark data available for development, testing and comparison of CV-based methods is limited. This problem has been partially overcome in recent years by the use of the physics-based graphical models (PBGM) in generation of synthetic but realistic video data [3].

In this work, a comparison of two popular methods of CV-based object tracking applicable in SHM is discussed. PBGM-based videos used in this study are a part of *"The 2nd International Competition for Structural Health Monitoring"* [1]. Exact structural displacements are available due to the fact that PBGM-based video are generated using the structural model. Hence, calculation of the error metrics is straightforward and reliable. The PBGM-based videos show a spatial truss subjected to an unknown excitation (Fig. 1).

2. Computer vision-based methods of estimation of the dynamic displacements

Two popular methods are tested on the PBGM-based video:

Normalised cross-correlation-based template matching (NCCTM). Template matching is one of the most accurate and popular methods of object tracking due to its relatively high accuracy. Displacements of the joints are estimated as the position of the template, including tracked truss node, that is matched with a sub-region of a usually larger region of interest (ROI) in the currently processed video frame. In this case matching is obtained by maximization of the normalized cross-correlation (NCC) between the template and the ROI. In order to achieve a sub-pixel precision, the NCC is interpolated with an eight times denser mesh.

Kanade–Lucas–Tomasi algorithm with repetitive correction (KLT-RC). In this case, the problem of the estimation of the nodal displacements can be divided into three parts. The first part is the initiation of the algorithm by extraction of the corner points in manually selected ROIs (Fig. 1) with the Harris–Stephens detector.

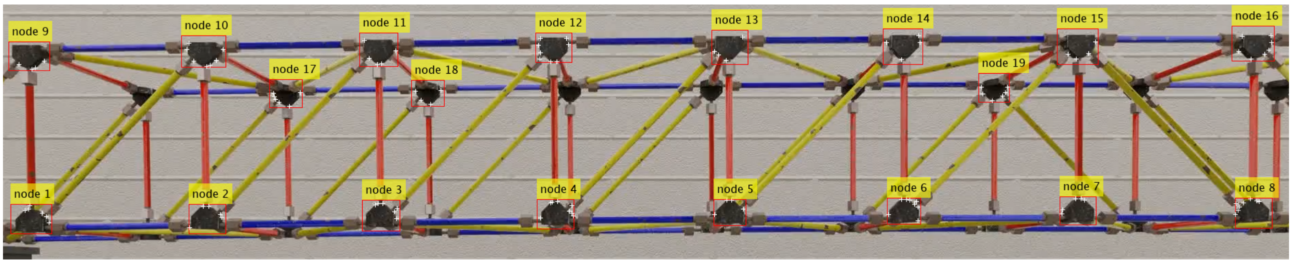

Figure 1: Frame of a PBGM-based video showing the investigated truss structure, manually selected truss nodes (marked by the red rectangles) and extracted corner points (marked by the white crosses "+")

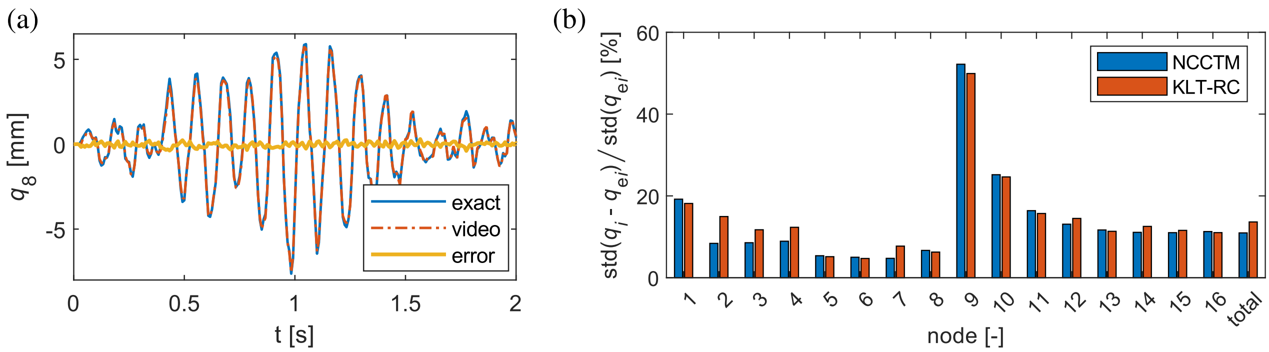

Figure 2: (a) vertical displacements of the 8th node obtained with the KLT-RC method and (b) comparison of the standard deviation of the estimation error in relation to the standard deviation of the exact displacements, q_i – vertical displacements of ith node, q_{ei} – corresponding exact displacements

The second part is tracking the points with Kanade-Lucas-Tomasi (KLT) algorithm that minimizes the sum of the squared differences between the subsequent movie frames in the neighborhood of the extracted corner points. Estimated displacement between subsequent frames is added to the total displacement of the truss node. Such an incremental approach results in error accumulation during long-term tracking. Thus, in the third part of the algorithm, a repetitive correction of the nodal position with the aid of feature matching is employed.

3. Results of comparison

The PBGM-based video with full-HD resolution and the frame rate (equivalent of the sampling frequency) of 120 fps are used for object tracking. Exact vertical displacements of the nodes 1–16 are known. As an example, the vertical displacement extracted from the video for node 8 with the KLT-CR method is compared with the exact value in Fig. 2a. Relative estimation errors for each node and for all nodes are shown in Fig. 2b.

Averaged error for the NCCTM is 10.1 %, whereas for the KLT-RC it is 13.6 %. The estimation error is significantly greater for the nodes close to the structure supports (1st and 9th node, Fig. 1). The reason is the fact that smaller displacements result in a greater sensitivity of the tracking to disturbances. Moreover, the response of these nodes has a relatively larger participation of higher order modes. The NCCTM is less efficient in terms of the tracking frame rate which is 3.6 fps, while the KLT-CR achieves the frame rate of 100 fps.

4. Conclusions

Both tested methods, NCCTM and KLT-RC, achieve comparable accuracy for the tested PBGM-based video. The NCCTM is more accurate (10.1 % vs 13.6 % of the noise level) but much slower (3.6 fps vs. 100 fps). Thus, the choice depends on the application of the CV-based measurement.

Acknowledgments The authors gratefully acknowledge the support of the National Science Centre, Poland, granted under the grant agreement 2018/31/B/ST8/03152.

References

[1] The 2nd international competition for structural health monitoring (IC-SHM, 2021).
[2] T. Nagayama and B. F. Spencer. *Structural Health Monitoring Using Smart Sensors*. The Newmark Structural Engineering Laboratory, University of Illinois at Urbana-Champaign, 2007.
[3] Y. Narazaki, F. Gomez, V. Hoskere, M. D. Smith, and B. F. Spencer. Efficient development of vision-based dense three-dimensional displacement measurement algorithms using physics-based graphics models. *Structural Health Monitoring*, 20:1841–1863, 2021.
[4] B. F. Spencer, V. Hoskere, and Y. Narazaki. Advances in computer vision-based civil infrastructure inspection and monitoring. *Engineering*, 5:199–222, 2019.