Bulgarian Society for NDT
International Journal "NDT Days"
Volume II, Issue 4, Year 2019

ISSN: 2603-4018
eISSN: 2603-4646

Digital Image Correlation for Monitoring of Timber Walls

Georgi STOILOV, Dessislava PASHKOULEVA, Vassil KAVARDZHIKOV

Institute of Mechanics at the Bulgarian Academy of Sciences, Sofia, Bulgaria,
e-mail: dessip@imbm.bas.bg

Abstract
The full-field optical technique based on digital image correlation (DIC) is a tool that is gaining popularity as a way to capture more detailed information about deformation fields of objects. The present work reports results of preliminary tests for monitoring of timber walls applying this method. Efforts were dedicate to develop a software, as well as to arrange and calibrate a DIC system which to be implemented for performing remote measurements of a timber wall deformation fields. It is shown that this DIC system allows one to obtain quantitative information about the complete fields of displacement in areas where other experimental devices (for example the strain gauges) are not so effective. The system would not replace the assessment of complex interactions in wall bearing loads with standard methods but can deliver additional information about deformation process.

Keywords: Digital image correlation (DIC), monitoring, timber wall, quasi-static test, displacement field

1. Introduction

The full-field optical technique based on digital image correlation (DIC) is a tool that is gaining popularity as a way to capture more detailed information about deformation fields of objects. This is linked with the development of the image digitization technology. In DIC, the monitored object is photographed with a digital camera before, during and after a load. The change of a random pattern applied on the observed surface is tracked through consecutive pattern images. The basic principle of the DIC method consists in finding the correlation between individual pixels of two digital images [1, 2]. The relative difference between coordinates of the geometric centers of group adjacent pixels (the so called "subset") in the object surface image before deformation and after deformation corresponds to an absolute displacement of these points on the deformed object surface. This advanced method is related with the development and the application of correlation algorithms for full-pixel and sub-pixel displacements.
At present, the DIC method is widely utilized of in experimental mechanics, because it can be used for almost all kinds of tested material (wood, metal, ceramics, polymers, natural tissues), at huge scale of digital images (from micrometers to tens of meters) and relatively acceptable initial costs.
It is well known that the timber is one of the oldest building materials and timber walls (structures) have been used for many hundreds of years. There are varied studies applying DIC for research reaction wood at different loadings: compression [3], tension [3, 4], bending [5]. For example in [3] a description of variability of the visco-elastic behaviour of wood during the long-term compression and tension loading is presented. DIC is used successfully to determine stress-strain state of wood specimens [4]. Authors determined the orthotropic elastic engineering parameters of the material such as Young's moduli, shear moduli and Poisson's ratios of four different wood species while tension samples were used. In [5] are obtained the mechanical parameters of palm wood registering images of its structure at different scales. After that, this information is utilized for the designing of polymeric composites possessing similar structure. Evaluation of DIC technique applicability together with finite-element modelling for determination of energy release rate in orthotropic wood loaded in the fracture mix-mode is reported in [6].

All these articles illustrate the potential of DIC method for studies in mechanics of wood materials. Therefore, utilization of DIC also for monitoring of timber walls can be recommended. DIC allows the civil engineers to solve such kinds of tasks as remotely detecting, measuring and tracking changes in deformation fields of their surfaces with high precision. For example in [7] is demonstrated application of the method to derive data upon seismic-resistant behavior of timber-framed structures filled with stones. In order to better understand the mechanical effects of a ladder-like timber insertions, in [8] is compared the behavior of reinforced and unreinforced masonry walls when submitted to in-plane shear loads. A group at the Faculty of Structural Engineering, University of Architecture, Civil Engineering and Geodesy is working on a similar subject. A group at the Faculty of Structural Engineering, the University of Architecture, Civil Engineering and Geodesy is working on a subject connected with numerical analysis of the post-and-plank timber walls [9].
The work presented here focuses on preliminary tests in the monitoring of timber walls by means of DIC. Efforts were dedicate to develop a software, as well as to arrange and calibrate a DIC system which to be implemented for performing remote measurements of a timber wall deformation fields.

2. DIC instrumentation and measurement procedure

The experimental setup used in this study is includes the following elements: one digital recording unit (camera fitted with a CMOS sensor), a lens, a tripod, a source of white diffuse light, a computer unit with adequate computing power and software for the processing (calculation of correlation coefficients, displacement, strain).
A camera Sony Alpha a6000 is used with CMOS sensor (23,5 x 15,6mm) possessing a maximum resolution of 6000x4000 pixels and a frame rate of up to 11 images per second. The lens focal length is 50 mm. Camera's optical axis was adjusted to be orthogonal to the studied surfaces, which are illuminated by white light sources. The distance from camera to monitoring surface is kept invariant during the experiment.
Any DIC system has to be calibrated before usage. Due to that preliminary tests are conducted in the lab. A part of calibration procedure includes a transform the displacement of the object surface from pixel units to the appropriate physical units. For that purpose, it is necessary to find out how many pixels in the image correspond to a length unit on the actual object surface i.e. we are determine the conversion factor. Two markers are placed on the investigated surface, the distance between them being known in physical length units. The direct pixel distance between the markers is determined and the conversion factor is calculated at every scale of imaging. A sequence of pictures of the object from different distances is shot to determine the optimal measurement scale. Series of in-plane motions at every scale are applied to monitored object. Both horizontal and vertical translations were put using micrometers mounted on two conjugated translation tables. With this calibration procedure it is proved that the measurements are with high level of accuracy.
Another task which has to be solved before starting the real measurements is the optimization of subset size. It depends on several variables as image resolution, contrast, magnitude and character of deformation field. Rectangular subsets of size from 16 × 16 to 256 × 256 pixels are studied. It is well known that, in DIC algorithm realization, smaller subset size ensures higher spatial resolution in measuring of deformation fields and reduces the volume of calculations (and respective -calculation time) for finding corresponding points of two images. But a subset size reduction leads to reduction the accuracy of correlation peaks localization, reducing at the same time measurement accuracy. That is why a compromise subsets size 32×32 pixels was chosen.

With these laboratory and numerical tests was evaluated that our DIC system is capable to measure changes in position of any point on the monitored surface from distance 3 meters with accuracy of 1 millimetre. Distortions of the lens were also taken in to consideration.
To further establish the accuracy in real test situations, a quasi-static test on a timber wall is performed (Fig.1). The wall was constructed in the laboratory at the Faculty of Structural Engineering, the University of Architecture, Civil Engineering and Geodesy. The loading device consists of two pneumatic cylinders (for horizontal x and vertical y directions). Several inductive gages are mounted on the timber wall (on the back site) for additional control and measurement of local displacement. To simulate permanent loads a constant vertical load of 21 kN was applied to the wall. The horizontal load was applied until failure. Due to applying loads the timber wall is deformed only in the x and y directions it is supposed that there is no movement of the surface in direction perpendicular to the xy plane (i.e. along z direction).

Fig. 1. Experimental setup with tested timber wall

The creation of a random speckle pattern which has to be applied to the surface is important for DIC method implementation as this task is closely related to the accuracy and spatial resolution of measurements. There is not a universal speckle pattern. Therefore, part of the preliminary preparation consists of applying a random pattern with good contrast to the surface of the timber wall. An important requirement is the pattern to follow exactly deformations of object surface to which it is attached. If this requirement is not satisfied errors in measured real displacements would arise in result. The method of generating random patterns is explained in detail in our previous publications [10, 11]. The initial pattern is a "white noise" image, synthesized by a random number generator. The spectrum of this image in the spatial frequency domain is subjected to filtration through a two-band transmission filter in order to maintain the same image contrast for all frequency domains. A sample of binary images of random speckle pattern, which we use for the purposes of the present work, is shown in Fig. 2. The speckle pattern is generated by computer using library OpenCV and Visual Studio 2017 based software. It is applied by offset printing technique on a planks building the timber wall.
Entire process was tracked by acquisition totally 1200 incremental images taken in 2 seconds in the process of load increasing with total duration two hours. The numerical values of applied

forces reading from respective sensors were also recorded at the same time. Special software developed by the authors within "Microsoft Visual C++" environment, is used for data analysis and displaying the resulting 2D displacement field information. This software manages the operation of camera, too. Additionally the program displays the wall's images of course.

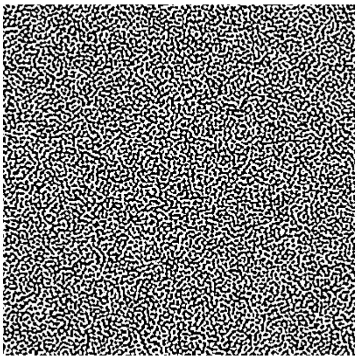


Fig. 2. Speckle pattern ready for use to a physical experiment

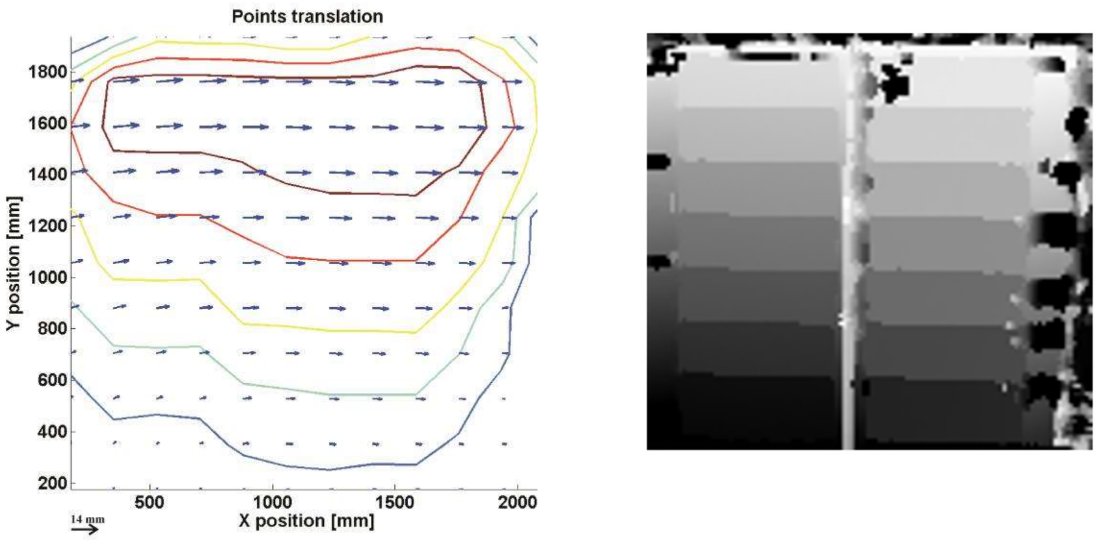
3. Examples of Measured Results

Figure 3 presents the first (a) and the last (b) acquired images.

(a) **(b)**

Fig. 3. Camera images in the beginning (a) and the end (b) of the experiment

Figure 4a shows the horizontal displacement field in *xy* plane obtained by integrating displacement vectors at respective points, which have been calculated after correlation analysis of 41 images in one minute, i.e. within duration 41 min after the experiment start. One of vertical loading device screws is imaged in Fig. 4b (see this screw also in Fig. 3). (This area have been eliminated by software processing, due to that it cannot be seen in Fig. 4a). Movements as a solid body in *x* direction to each of the horizontal planks are encoded by the variations of the gray colour of in Fig. 4b. As can also be seen from Fig. 4a, the bottom board has a less movement (black colour), and the top board has the largest movement (almost white colour). The maximum value of displacement is 14 mm. It should be noted that the planks were not bonded. That is why in Fig. 4b the number different displacement regions is equal to the number of planks.



(a) (b)

Fig. 4. Horizontal displacement field obtained with DIC: (a) displacement vectors (b) variation of gray

4. Conclusion

This paper introduces system based on the principals of digital image processing applying to monitoring of timber walls. We show that this DIC system allows one to obtain quantitative information about the complete fields of displacement in areas where other experimental devices (for example the strain gauges) are not so effective. At the same time, these systems prove to be simple, robust and affordable. The monitoring system does not aim to replace the assessment of complex interactions in wall bearing loads with standard methods. It rather offers additional information to guarantee a safe working environment. The system will be used at upcoming systematic and complex studies the behaviour of wooden walls subjected to loading, as well as for solving tasks related to the structural health monitoring of other engineering structures.

Acknowledgement
This study has been partially financial supported by of assoc. prof. Kiril Minchev from Section Mechatrol, Notified Body NB1938, Institute of Mechanics. The experiments have been done at the Faculty of Structural Engineering, the University of Architecture, Civil Engineering and Geodesy, Sofia.

References

1. Hild F., S. Roux. Digital Image Correlation: from Displacement Measurement to Identification of Elastic Properties - a Review. Strain, Vol. 42, No. 2, 2006, pp 69-80.
2. Pan B., K. Qian, H. Xie, A. Asundi. Two-dimensional Digital Image Correlation for In-plane Displacement and Strain Measurement: a Review. Meas. Sci. Technol., Vol. 20, No. 6, 2009, pp 1-17.
3. Ozyhar T., S. Hering, P. Niemz. Viscoelastic Characterization of Wood: Time Dependence of the Orthotropic Compliance in Tension and Compression. J. Rheol., Vol. 57, No. 2, 2013, pp 699-717.
4. Jeong G.Y., M.J. Park. Evaluate Orthotropic Properties of Wood using Digital Image Correlation. Constr. Build. Mater. Vol. 113, 2016, pp 864-869.

5. Haldar S., N. Gheewala, K.J. Grande-Allen, M.A. Sutton, H.A. Bruck. Multiscale Mechanical Characterization of Palmetto Wood using Digital Image Correlation to Develop a Template for Biologically-Inspired Polymer Composites. Exp. Mech., Vol. 51, No. 4, 2011, pp 575-589.
6. Méité M., F. Dubois, O. Pop, J. Absi. Mixed Mode Fracture Properties Characterization for Wood by Digital Images Correlation and Finite Element Method coupling. Eng. Fract. Mech., Vol. 105, 2013, pp 86-100.
7. Sieffert Y., F. Vieux-Champagne, S. Grange, P. Garnier, J.C. Duccini, L. Daudeville. Full-field Measurement with a Digital Image Correlation Analysis of a Shake Table Test on a Timber-framed Structure filled with Stones and Earth. Engin. Struct., Vol. 123, 2016, pp 451-472.
8. Crété E., S. Yadav, M. Hofmann, F. Vieux-Champagne, Y. Sieffert, O. Moles, Ph. Garnier. Timber Seismic Bands: Correlating their Characteristics with Local Seismic Activities and Understanding their Effects under Seismic Loads. Proc. of Inter-ISC'18, Turkey, hal-02004219.
9. Gruewa P., V. Tanev. An overview of the structural details and numerical analysis of the post-and-plank timber walls in the Kotel region in Bulgaria. Proc. of ICOMOS Inter-ISC Meeting & Colloquium, Turkey, 2018, pp 83-91.
10. Stoilov G., V. Kavardzhikov, D. Pashkouleva. A Comparative Study of Random Patterns for Digital Image Correlation, J. of Theor. and Appl. Mechanics, Vol. 42, No. 2, 2012, pp 55-66.
11. Stoilov G., V. Kavardzhikov, D. Pashkouleva. Multiscale Monitoring of Deformation Fields by Digital Image Correlation Method, J. of Theor. and Appl. Mechanics, 48 (4), 2018, pp 23-40.