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Open Source 2D DIC Tools for Applications in Solid Mechanics

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Abstract: Open source 2D digital image correlation (DIC) tools are introduced in the presented paper and simple rules to obtain accurate and reliable results are proposed. The use of the DIC tools when analyzing the development of displacement or strain fields on a surface of a loaded structure or specimen can significantly reduce the cost of the experiment and provide more accurate data, compared to conventional contact methods. Numerous studies, e.g. a study to investigate the development of multiple cracking in fiber reinforced high-performance concrete, demonstrated a computational feasibility, accuracy and sensitivity of the method for a relatively low cost.

Keywords: DIC; Open Source Software; Strain Field; Displacement Field; Optical Measurement.

1 Introduction

There are various techniques in the field of experimental analysis of materials and structures to measure the surface deformation. In the engineering practice the displacements and deformations are conventionally measured at pre-determined locations by means of extensometers or strain-gauges. However, such approach has a number of limitations — the strain must be within a certain range and is averaged over the strain-gauge length, the measurement is limited to the strain-gauge location and sometimes also to its orientation, and the surface of the loaded element must be smooth enough to attach the gauge. Moreover, the results are often influenced by an improper attachment of a strain-gauge or extensometer to the monitored surface. Full-field non-contact measurements of deformation employing optical monitoring overcome these limitations and capture even complex deformation until the ultimate failure of the observed surface [1].

DIC is an optical method to determine image motion and distortions [2], exploited as an experimental tool to track displacement and strain fields of a surface texture or a stochastic pattern applied onto the specimen surface. To that goal, a subset of gray-scale pixels in the reference image (representing the initial state) is matched to a similar subset in the target image of a deformed surface.

Such a full-field approach allows an efficient observation of localization phenomena where the conventional contact methods fail, such as necking in metals, crack initiation in brittle materials, or deformation of textiles and rough surfaces. Moreover, the averaging of strains is also minimized and depends purely on the resolution of images. However, a portion of data can be easily lost after spalling of the surface layer as usually happens in the case of brittle materials subjected to severe loading.

Several studies deal with evaluation of errors in the field of displacements and deformations obtained by DIC and show a relatively good accuracy of the method, e.g. [3]. As non-commercial scientific software packages emerge, the method becomes feasible for common laboratory measurements. The purpose of this contribution is to introduce open source 2D DIC tools operating in MATLAB environment [4], namely DIC code developed at Georgia Institute of Technology by Antonia Antonious group, Ncorr [5], and the DIC data post-processing tool developed by the author at Czech Technical University in Prague, Ncorr_post [6].

2 DIC

The main idea of DIC is to find a correspondence between control set of points in reference and current images, which is accomplished by tracking small subsets of the reference image, and determining their locations in the current images. Displacement and strain information are obtained through transformation relations used to match the location of the subset in the current (deformed) states for each subset. The subsets are selected in the reference configuration with a certain spacing to reduce computational cost.

The output of DIC is provided in the form of a matrix containing displacement and strain information, and the strains and displacements can be interpolated to form a continuous strain / displacement field. Detailed information about the DIC algorithms can be in e.g. in the papers by Pan et al. [3] or Lu and Cary [7].

2.1 Preparation of Input Images

The maximum resolution and accuracy of DIC results relies the quality of a contrast pattern applied on the monitored surface [8–10]. The pattern can be either in the form of a natural texture or it can be applied artificially. The pattern must be always random, isotropic, and highly contrasting, for illustration see Fig. 1. A common white wall-paint can be used to create the white background; it must be perfectly bonded to the monitored surface while forming just a thin layer, which is not provided by synthetic varnishes or enamels [9].

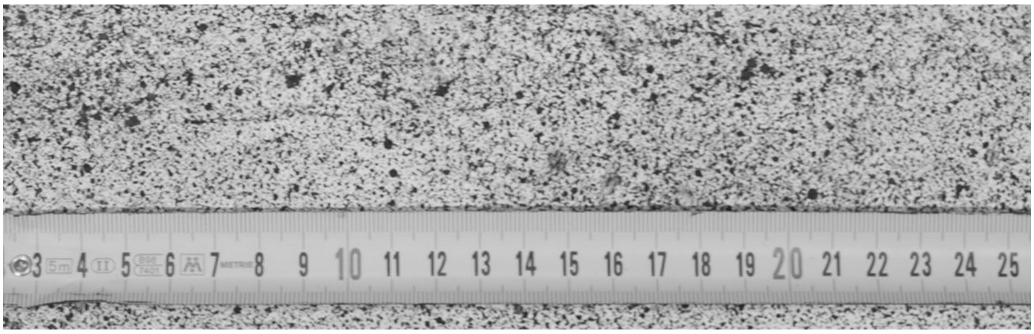

Fig. 1: Artificial stochastic contrast pattern.

For purpose of image acquisition it is recommended to use a digital high-resolution camera fixed on a tripod. The camera has to be placed parallel to the specimen surface. The distance of the camera from the observed surface and focal length must be adjusted in such a way to mitigate the lens distortion effect [11].

2.2 Calculation and Post-Processing of Results

Ncorr code for 2D DIC is provided together with a comprehensive manual at the official program website[1]. As in the majority of commonly used commercial packages, a general workflow of the DIC in Ncorr consists of:

1. *setting a reference image*: undeformed, reference image has to be loaded first,
2. *setting current images*: current images of deformed surface are loaded next using memory friendly "Load Lazy" option or faster, yet more demanding, "Load All" option,
3. *setting region of interest*: it can be defined drawn directly or defined by a matrix of logicals representing individual pixels,
4. *setting DIC parameters*: the algorithm based on Bi-Pan's RG-DIC framework [11] requires to set primarily the subset size and subset spacing — the main idea is to select the smallest possible subset to obtain non-noisy displacement data,
5. *setting solver options*: iteration criteria and multithreading options (enabling calculations on more processor cores simultaneously) have to be set,
6. *formatting displacements*: beside the cutoff of the noisy displacement values, a lens distortion effect can be compensated using a correction coefficient,
7. *strain analysis*: strain fields are evaluated based on a least-square plane fit of the displacement data and the Green-Lagrangian strains are calculated from the averaged displacement,

[1] http://www.ncorr.com

8. *plotting of results*: Ncorr provides a user-friendly menu to plot individual displacement or strain maps, however, advanced options are provided in Ncorr_post extension introduced next.

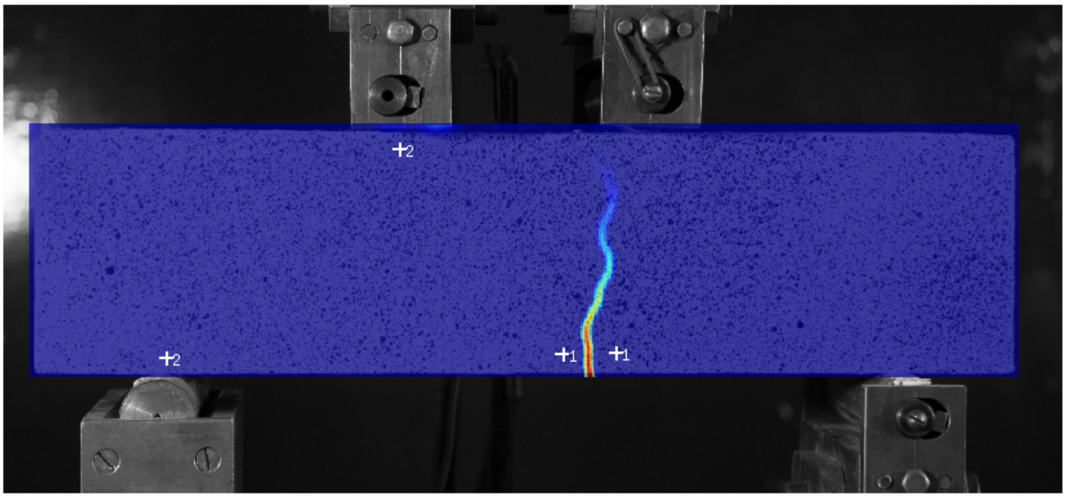

Fig. 2: Placement of virtual extensometers (denoted by numbered marks) on the specimen surface subjected to four-point bending test.

Ncorr_post is an open-source DIC post-processing tool. The program can load a previously saved project or directly the data structure from Ncorr. Beside the basic plotting options, provided in the post-processing menu of Ncorr, the program adds new features such as

- scaling the displacement field from pixels to physical units,
- bulk export of images with predefined properties and scaling,
- export of videos capturing strain or displacement development,
- placement of virtual extensometers and recording of relative displacements (Fig. 2), and
- representation of magnitude and direction principal by means of arrow indicators (Fig. 3).

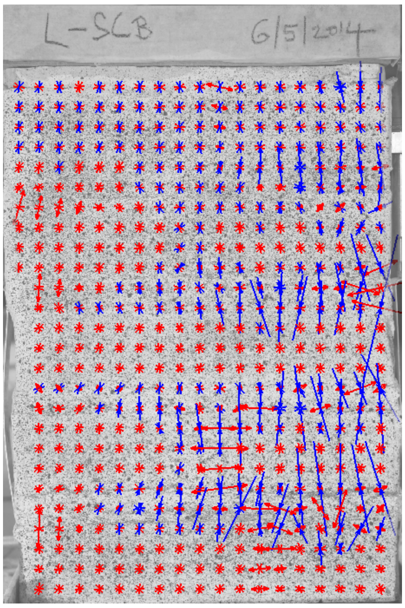

Fig. 3: Magnitude and direction of principal strains on the surface of a loaded masonry pier.

The approach and computer tools mentioned here were efficiently utilized e.g. when studying the development of multiple cracking and strain-hardening behavior in high performance concrete or formation of cracks and plastic zones in masonry piers subjected to a combination of compression and bending. The results conclusively indicate the independent optical measurement and DIC processing of images can provide much more accurate results than LVDT sensors. These very often overestimate the measured displacements because of the additional compliance of the loading frame.

3 Conclusion

Open source 2D DIC tools, namely Ncorr and Ncorr_post developed at Georgia Institute of Technology and Czech Technical University in Prague, respectively, offer rather advanced functionalities and can be efficiently exploited in experimental analysis. To obtain reliable input data, several rules regarding a proper illumination, contrast pattern applied at the specimen surface, camera setting or processing of images have to be followed.

Beside the qualitative representation of results, the method can be also used for quantification of displacements and deformations. The relative displacement of selected points can be monitored using virtual extensometers. Such an approach significantly reduces the cost of the measurement and provides reliable data because of independence of the camera on the tested sample or a loading frame.

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