LOW COST EXPERIMENTAL SETUP FOR 2D DIGITAL IMAGE CORRELATION METHOD

NISKO CJENOVNI EKSPERIMENTALNI POSTAV ZA METODU 2D KORELACIJE DIGITALNE SLIKE

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Abstract: *Two-dimensional (2D) Digital Image Correlation (DIC) is a widely used experimental method for measurement of in-plane displacement and strain. Commercial DIC experimental setups which are offered on the marked are quiet expensive. In this research, an alternative low cost 2D DIC experimental setup was presented, which is applicable in scientific research, as well as for industrial purposes. In order to validate and verify the experimental setup, an experiment in form of simple tension test of PTFE specimen has been conducted. Experimental results were compared with results obtained from finite element analysis (FEA).*

Key words: *Digital image correlation (DIC), experimental setup, low cost, Ncorr, PTFE*

Sažetak: *Dvodimenziijska (2D) korelacije digitalne slike (DIC) je široko primjenjivana eksperimentalna metoda koja se koristi za mjerenje pomaka i deformacija u ravnini. Komercijalni DIC eksperimentalni postavi dostupni na tržištu prilično su skupi. U ovom istraživanju predstavljen je alternativni niskocijenovni eksperimentalni postav, koji se može primjenjivati u znanstvenim istraživanjima, ali isto tako i u industrijske svrhe. U svrhu validacije i verifikacije eksperimentalnog postava, proveden je eksperiment u obliku jednostavnog vlačnog testa na epruveti od PTFE-a. Eksperimentlni rezultati uspoređeni su s rezultatima dobivenih pomoću metode konačnih elemenata (MKE).*

Ključne riječi: *Korelacija Digitalne Slike (DIC), eksperimentalni postav, niska cijena, Ncorr, PTFE*

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1. Introduction

Digital Image Correlation (DIC) is an optical non-contact experimental technique used in mechanics to measure full field displacements and strains. It's being applied in various engineering fields [1] because of its comparatively simplicity, robustness and inexpensive equipment relative to other optical methods such as holographic, moiré and speckle interferometry. 2D DIC is used to get simple in-plane displacements of flat surfaces, while 3D DIC provides in- and out-of-plane displacements of curved or planar surfaces. The method was originally introduced in the 1980s [1], but its stronger development took place in the last decade, parallel with the development of digital cameras and computer technology. The basic concept of DIC is to record a set of digital images of the specimen surface from the un-deformed to deformed state. The recorded images are then step by step compared and analysed using special DIC software, which is able to create displacement and strain field plots. Before conducting the experiment, simple preparation of the specimen surface in form of random speckle pattern application is required. Typical hardware for 2D DIC consists of one high resolution camera, lens, light source, and equipment for application of speckle pattern. For 3D DIC the use of two or more high resolution cameras is required.

2. Basic concept of 2D DIC

The basic concept of DIC method is to use image registration algorithms to track relative deformation of a random pattern between undeformed (reference) and deformed (current) image(s). To track the deformation between reference and current image, the reference image is divided into smaller local regions, called subsets (n x m pixel area), and tracked in the current image. Such DIC algorithms are referred to as subset-based [1]. Requirement for the images is to be grey scale. This is important since the comparison of two images is performed by means of two-dimensional cross correlation analysis. Several functions exist to match the subsets from one image to another. One of them is based on the minimum value of mutual cross coefficient $r(i, j)$ [3]:

$$r(i,j) = 1 - \frac{\sum A(i,j)\cdot B(i^*,j^*)}{\left(\sum A(i,j)^2 \cdot \sum B(i^*,j^*)^2\right)^{1/2}} \tag{1}$$

where $A(i, j)$ is the grey level (light intensity) at the location of (i, j) in the reference image, and $B(i^*, j^*)$ represents the grey level (light intensity) at the location of (i^*, j^*) in the current image. The relationship between (i, j) and (i^*, j^*) could be described as follows [3]:

$$i^* = i + u \tag{2}$$

$$j^* = j + v \tag{3}$$

where u and v represent the displacement of the pixel of (i, j) in the horizontal and vertical directions.

3. Low cost experimental setup

The purpose of this research was to investigate an alternative low cost experimental setup for 2D DIC covering equipment and procedure for specimen surface preparation, alternative equipment for image acquisition (camera, lens & light source), and software for DIC analysis (post-processing).

3.2 Preparation of Specimen Surface

Before conducting the DIC experiment a fairly uniform and random speckle pattern with good contrast needs to be applied on the specimen surface. The pattern is supposed to deform along with the specimen without falling away from it. Surface preparation is one of the crucial steps in DIC since the speckle pattern impacts the quality of the results. Although the application procedure is quiet simple, certain skills and experience is required by the researcher. There are several techniques to apply the pattern, one can use a spray can, brush, stamp or airbrush. Different techniques result in different speckle sizes. Generally, finer speckle pattern lead to greater accuracy of the results. In this research, the specimen has been patterned with self-adhesive black and white matte paint (non-reflective) using a spray can as shown on Figure 1 (a). Figure 1 (b) shows an exaggerated view of the randomly applied speckle pattern.

(a) (b)

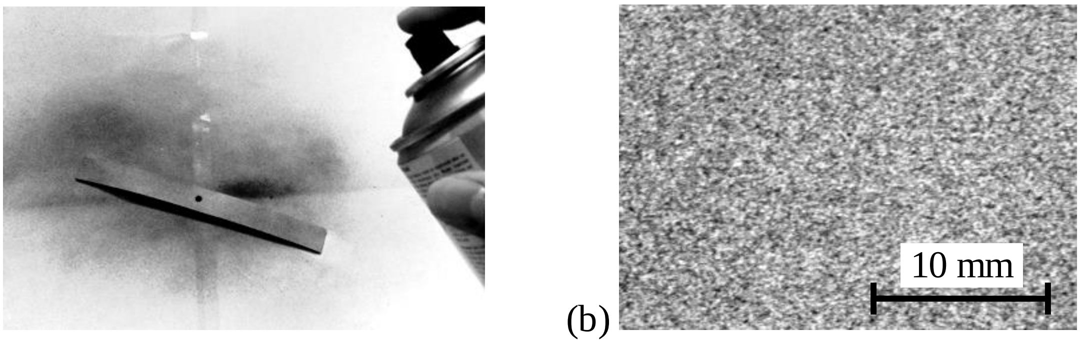


Figure 1. Preparation of specimen surface (a) & size of speckle pattern (b)

3.2 Digital Camera, Lens & Light Source

The image acquisition equipment for 2D DIC consists of a one high resolution CCD or CMOS camera, lens and a light source for illumination of the tested specimen surface as shown on Figure 2. The camera is positioned perpendicular to the specimen surface, while the specimen loading is nominally in-plane, with minimized out of plane motion.

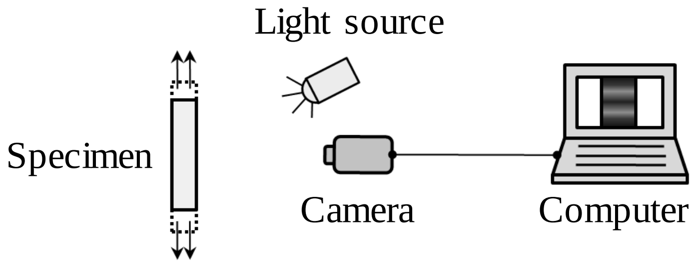


Figure 2. Experimental setup for 2D DIC

Commercial DIC setups available on the market use expensive scientific grade cameras, which mostly comprise a full-frame CCD (or CMOS) sensor. Instead of scientific grade camera, in the present research semi-professional digital single lens reflex (DSLR) camera *Canon EOS 350D* with suitable lens *Canon EF 28-135mm f/3.5-5.6 IS USM* has been used (Figure 3 (a)). The goal was to see if a DSLR camera could provide results that are comparable to scientific grade cameras. Successfully usage of a DSLR camera for DIC analysis was reported in [4]. General advantage of a semi-professional camera is the convenient quality-price ratio, as well as its availability (since most of people have it at home). Typical hardware for modern 2D DIC systems consists of scientific grade cameras costing around 4000–6000 USD [5] and its appropriate lens around 700 USD [5]. Cost of DSLR cameras with included lens is around 500–1000 USD and represents a significant cost saving. Technical specifications of the DSLR camera used in this research are given in Table 1.

Characteristic	**Value**
Sensor size	22.4 x 14.8 mm (CMOS)
Sensor resolution	3456 x 2304 pixels
Aspect ratio	3:2
Frames per second	3 fps

Table 1. Technical specification of DSLR camera *Canon EOS 350D* (2003.)

The DIC method does not require the use of lasers like some other experimental techniques; specimen surface can be simply illuminated by means of a high-intensity white-light source. However, it is recommended to use a light source which illuminates the specimen surface evenly and does not additional contribute to its reflection. In the present research a simple desk lamp as shown on Figure 2 (b) has been used, with mounted 23W CFL bulb which results in 1570 lumen brightness.

(a)  (b) 

Figure 3. DSLR camera Canon EOS 350D (a) & lighting lamp (b) used in the experiment

3.2 RAW vs. JPEG File Format

Semi-professional DSLR cameras have the ability to save the recorded image in two file formats: RAW and JPEG (or JPG). JPEG (Joint Photographic Experts Group) format processes and compresses the image right within the camera resulting in certain loss of information. On the other side, RAW is an uncompressed and unprocessed image format that captures all image details recorded by the sensor and results therefore in higher quality images. However, the disadvantage of RAW format is that images need to be viewed and processed by some commonly RAW converter software (e.g. Adobe Photoshop). In order to gain the best image quality for DIC analysis, in the present research RAW format has been used, and converted into PNG file format. This has been simply done by using free software available on the internet.

3.2 DIC Software

The recorded images of the specimen surface from undeformed to deformed state are stored in computer hard disk and analysed (post-processed) using DIC software. In this particular research the open source software *Ncorr* has been used. A huge advantage of using open source software’s is that they are completely free, representing a fairly good alternative in comparison to expensive commercial software packages. Commercial 2D DIC software packages with advanced processing features and an array of image accusation options cost on the order of 10000 USD [5]. *Ncorr* is a MATLAB based code [1] fairly simple for installation, and has an intuitive and user-friendly graphical user interface (GUI) as shown on Figure 4. The software user manual [6] describes steps from installation instructions up to suggestions for the overall DIC analysis. *Ncorr* has been verified by its authors in two published scientific papers [1] & [7], as well as in several publications utilizing *Ncorr* for experimental results or additional analyses [9]–[16]. DIC analysis in *Ncorr* can be roughly divided into following steps: (a) importing the reference (i.e. undeformed) image, (b) importing the current (i.e. deformed) image(s), (c) importing the region of interest image, (d) Setting DIC parameters, (e) Running DIC analysis & (f) Plotting displacements and strain fields. The image file format allowed for importation in *Ncorr* must either be JPEG, TIF, PNG, or BMP [6].

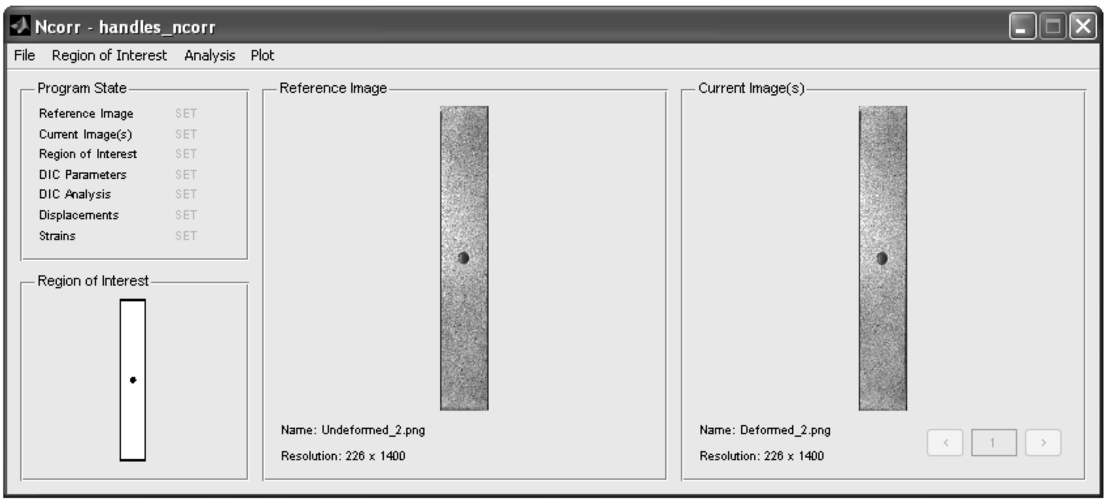


Figure 4. Graphical user interface (GUI) of *Ncorr*

4. Experimental Validation

In order to validate and verify the low cost 2D DIC experimental setup, an experiment has been conducted. Specimen with dimensions as shown on Figure 5 (a) was installed on a testing machine and subjected to deformation under uniaxial tensile loading. As shown on Figure 5 (b), the observed specimen length after installation on testing machine was l=150 mm. Specimen was made of Polytetrafluoroethylene (PTFE), a polymer material usually used for seals, bearings, wire insulation, valves, etc. [17].

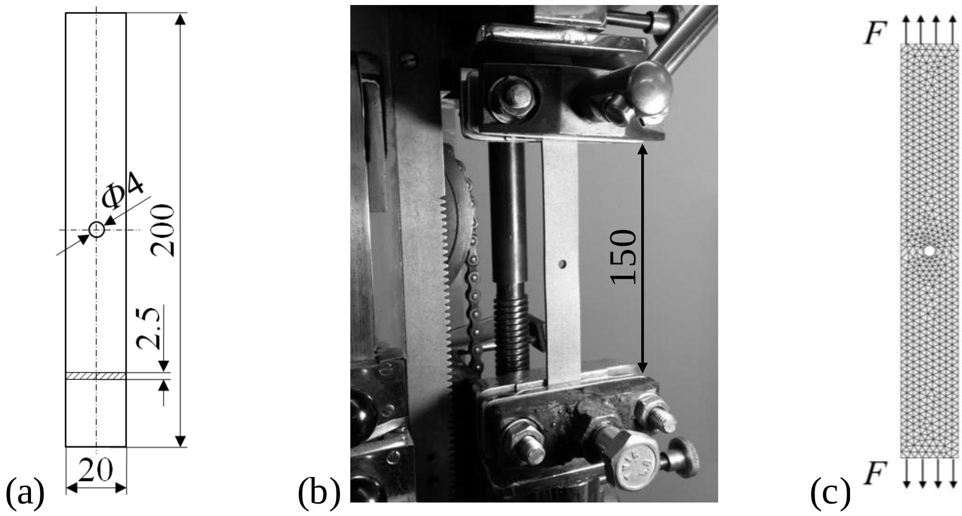
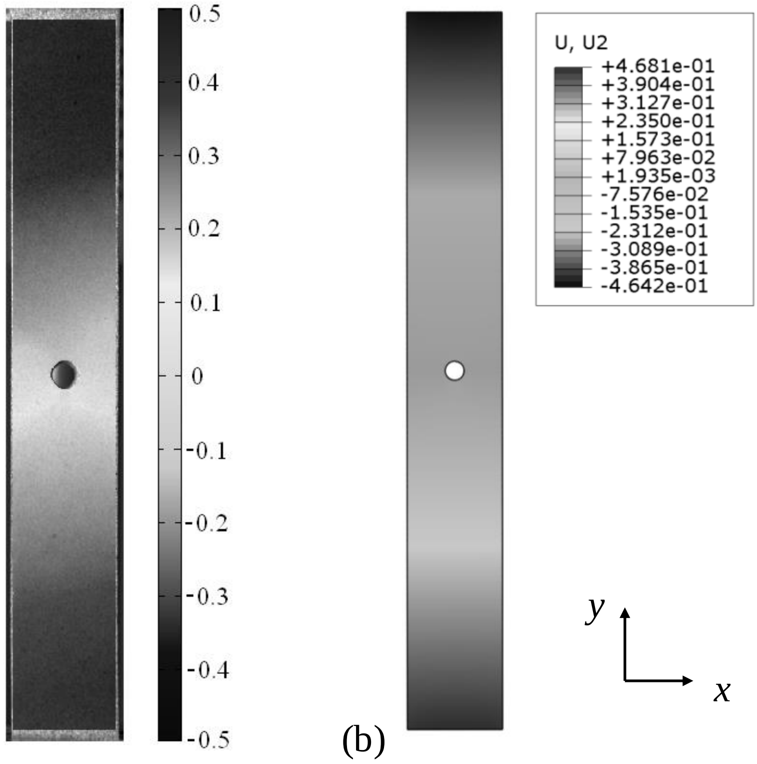


Figure 5. Specimen (all units in mm): (a) dimensions, (b) mounted on testing machine, (c) meshed FE model

The elastic response of PTFE begins to deviate from linearity at strains of only a few percent, as with most plastics [17]. In order to ensure elastic response, only a small amount of load (F=200 N) has been applied to the specimen ends. The applied loading has been controlled and measured directly on the testing machine. Measured ambient temperature during testing was 21°C.

The experimental setup has been arranged according to Figure 2. Camera was positioned in front of the specimen, perpendicular to the measured surface. The experiment itself has been conducted very carefully, isolating any possible equipment disturbance (vibrations, shaking, movement, etc.) which might negatively affect the image quality. First step of the experiment was to record the reference image of the un-deformed specimen surface. In the second step the specimen was subjected to tensile loading and the deformed image was recorded. By default the two images were stored in the memory of the camera and in the next step exported to computer where the actual DIC analysis in *Ncorr* has been performed. Figure 6 (a) shows experimental results in form of displacement field plot (in tension direction) of the specimen surface. As expected, peak displacements (±0.5 mm) are at the specimen ends, resulting in total specimen extension of Δl_{DIC}=1 mm. For comparison, analytical solution of uniaxial tensile case (neglecting middle hole) can be calculated using equation $\Delta l=Fl/AE$, which gives a value of Δl=0.92 mm.



(a) (b)

Figure 6. Comparison of displacement field in tension direction between (a) DIC analysis in *Ncorr* and (b) FE analysis in ABAQUS (units are in mm)

Results from the DIC experiment were compared with a finite element analysis (FEA) which was conducted in commercial software tool ABAQUS. Elastic material properties used for PTFE were: E=653 MPa for Young's modulus & v=0.46 for Poisson's coefficient. Figure 5 (c) shows the meshed FE model, which was modelled with second order tetrahedral elements (C3D10). Result of the FE analysis is shown on Figure 6 (b) in form of displacement field in tension direction. Peak displacements (±0.46 mm) are again at the specimen ends, resulting in total specimen extensions of Δl_{FEM}=0.93 mm. Comparing the total specimen extension gained from experiment results (Δl_{DIC}) with those from analytical (Δl) and numerical solutions (Δl_{FEM}), it becomes obvious that the difference is only 7–8 %. This represents a fairly acceptable difference considering that analytical and numerical solutions are idealized models, while in reality specimen has certain imperfections. Additionally, from Figure 6 it can be seen that there is a good correlation of displacement fields between experimental and numerical results.

5. Conclusion

Typical hardware for 2D DIC consists of one high resolution camera, lens, light source and equipment for application of speckle pattern. DIC method can be roughly divided into three basic steps: (a) preparation of specimen surface, (b) image acquisition of undeformed and deformed specimen surface and (c) analysis of recorded images in DIC software. Random speckle pattern is easily sprayed on the test surface to provide the required texture without affecting the mechanical behavior. In this particular research an alternative 2D DIC setup was presented, comparable to existing commercial 2D DIC measuring systems available on the market. The main advantage of the introduced setup is in first place its low price, without negatively affecting the result accuracy. This research showed that a semi-professional DSLR camera can be used instead of scientific grade camera in order to get the in-plane displacement and strains fields of the observed specimen surface. However, there are certain limitations. Sensor size plays a major role in the quality of the recorded images, but also affects the price of the camera. Generally, cameras which contain smaller sensor size then those used in this research should be avoided since this would lead to lower image quality then required. Additionally, DSLR cameras have a limitation in the number of pictures that can be taken per second (frames per rate). Because of this, it’s not possible to analyse any high speed dynamic process.

The present research shows that open source software’s *Ncorr* represent a fairly good alternative in comparison to expensive commercial DIC software packages. However, completely correctness of any of the resulting displacement and strain data obtained from *Ncorr* cannot be fully guaranteed [6]. Therefore, analytical or numerical methods such as FEM are a good way for cross-checking and verification of the experimental 2D DIC results. A disadvantage of the introduced setup is that it doesn’t provide real time results, but requires post-processing after conducting the experiment. This might lead to unwanted repetition of the experiment if the recorded images are of improper quality (e.g. blurriness).

Due to its low price, the proposed 2D DIC setup in combination with open source DIC software *Ncorr* makes the DIC method even more affordable to students, academic researchers and industrial engineers. Further development and investigation of the low coast 2D DIC setup are planned in future.

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