Experimentální Analýza Napětí 2010
Experimental Stress Analysis

# Optimization and Calibration of Digital Image Correlation method

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**Abstract:** An example of instrumentation and optimization of Digital Image Correlation measurement system for given class of experiments is described in this paper. Subsequent calibration of such experimental configuration via new Standardization Project for Optical Techniques of Strain Measurement (SPOTS) is presented.

**Keywords:** Digital Image Correlation, Calibration, Optimization

## 1. Introduction

The utilization of non-contact optical methods for strain and stress measurement in experimental mechanics has rapidly increased recently. Implementation and applicability of each such experimental method are limited by the knowledge of its accuracy and range of the measurable strains. However, so far these methods have suffered from a lack of standards, norms and optimised methodologies for metrological assessment. Recently developed standardization project for optical techniques of strain measurement (SPOTS) addresses these lacks [1]. The project defines a universal calibration specimen and experimental procedure which allow generating predictable (analytically defined) strains. The comparison of analytical solution and measured strains can be then analyzed using statistical methods and resulting uncertainties and errors of the optical measurement system can be determined. Recently, for instance, the calibration was successfully applied for ESPI system by E.A. Patterson et al. [2]. This paper deals with the calibration of digital image processing technique well known as 2D Digital Image Correlation (DIC) [3]. The technique utilizes a sequence of consecutive images that represents a deformation of a specimen planar surface. In this sequence DIC observes displacements of individual templates of some pattern employing a correlation technique. The template is a cutout of the pattern that contains a small but distinguishable part of the pattern.

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## 2. Instrumentation and optimization

Optimization of three essential components has to be involved for a given class of experiments (i.e. magnification, accuracy, material, loading etc.). These components are: optical system, treatment of the specimen surface and DIC algorithm. In the case of optical system, high resolution, low level of noise and stability are important parameters. 15 MPixel Canon EOS 500D digital camera with SIGMA macro lens was chosen as the appropriate device in this work. The own DIC software based on cross-correlation cost function [3] was employed for displacement vector field evaluation.

### *2.1. Treatment of the specimen surface*

A random pattern has to be produced on the surface of the specimen for DIC purpose. Most often, the pattern has the form of randomly distributed white speckles on the black background. An average size and distribution density of these speckles at given optical magnification are important parameters for DIC accuracy. Therefore, finding an ideal technology of such treatment of the specimen surface is necessary. In this work, the optimization is done for experiments where the region of interest is about (10~50)x(10~50) mm. The fine airbrush with black and white acrylic paint (Revell - Aqua Color) was employed in this case. The procedure of the treatment is following: First, the specimen is cleaned by clout with some cleaning agent. Then, the specimen surface is uniformly sprayed with black colour. This black layer should be very thin to ensure an identical deformation of the specimen and the paint. Finally, on the prepared black background, the white speckles are created by randomly shaking with airbrush with white colour.

The usability of the created pattern is estimated by means of a normalised auto-correlation function (NACF) of the typical pattern template. The estimation is associated with the width of the NACF at a pre-defined value, typically at 0.5. The standard says that an appropriate size of this width belongs to interval <3, 6> pixels [4]. In the Figure 1 (left) is shown the typical pattern template prepared by above described technology and its NACF (right). It is viewed that the width of the NACF at value 0.5 is about 6 pixels, thus near-optimal.

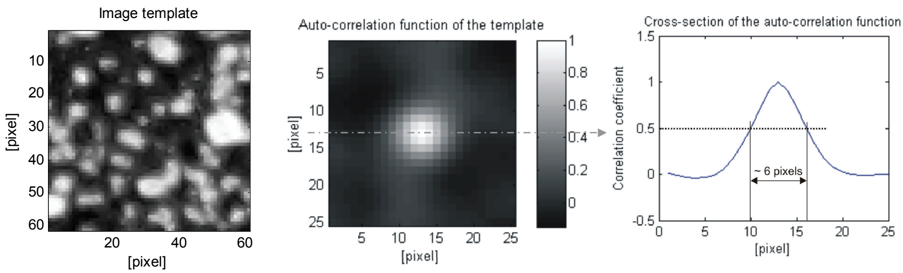


**Fig. 1.** Image template (61x61 pixels), left, normalised auto-correlation function (matrix of correlation coefficients) of the template, middle, cross-section of the auto-correlation function, right.

## 3. Calibration experiment

### 3.1. Specimen and material

The calibration reference specimen was manufactured according to the Physical Reference Material described in the SPOTS standard [1]. The specimen is based on a four-point bending test of a beam that is embodied in a monolithic design concept; see Figure 2 (left). The specimen can be made of any material and at any scale. The fully parametric design depends only on one parameter *W* (width of the beam). The specimen can be loaded in either tension or compression. The gauge section of the specimen intended for calibration procedure is the central square of the beam with dimension *WxW*. Analytical solution of strain components of this region can be obtained by means of beam theory, as follows:

$$\varepsilon_{xx} = -\frac{yd}{6W^2} \tag{1}$$

where *d* is the displacement load applied to the upper central loading points, *W* is the width of the beam and *y* is the *y*-axis in coordinate system of the specimen depicted in Figure 2 (right).

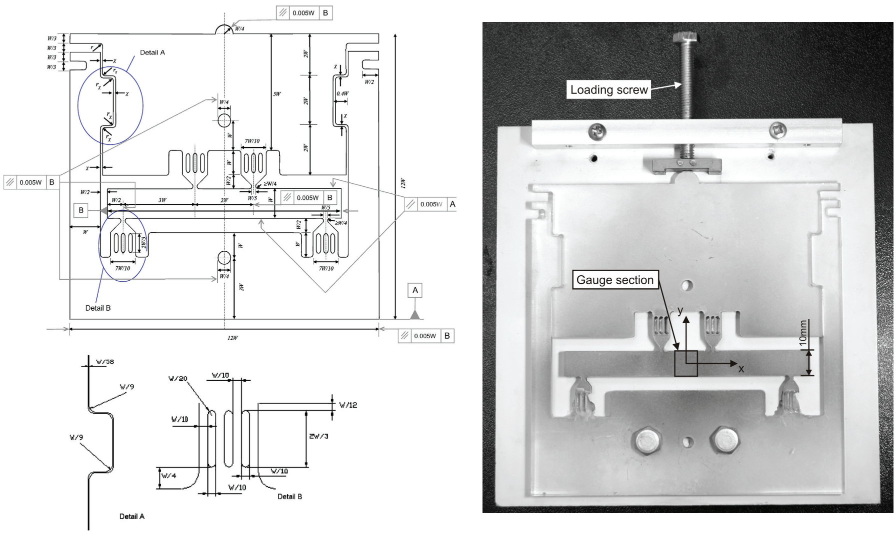


**Fig. 2.** Scheme of the monolithic calibration specimen based on a four-point bending of the beam (scheme takes from [1]), left, the manufactured specimen made of plexiglass placed into the loading device, the gauge section with orientation of coordinate system is highlighted, right.

In this work *W* was chosen 10mm in respect to the optical magnification demands. The specimen was made of plexi-glass. A simple loading device, allowing compression load by force of controlled displacement, was manufactured. The load is applied through the small half-cylinder on the top surface using srew, see Figure 2 (right).

*3.2. DIC*

The surface of the specimen was treated by the technology described in previous chapter. The specimen was placed into the loading device and $d$ = 632μm displacement increment was applied by the screw. This displacement was also measured by the DIC. Two images of the gauge section, before and after applied deformation, were recorded. The scale factor was 1pixel = 4.15μm. The images were stored in computer and prepared for DIC implementation.

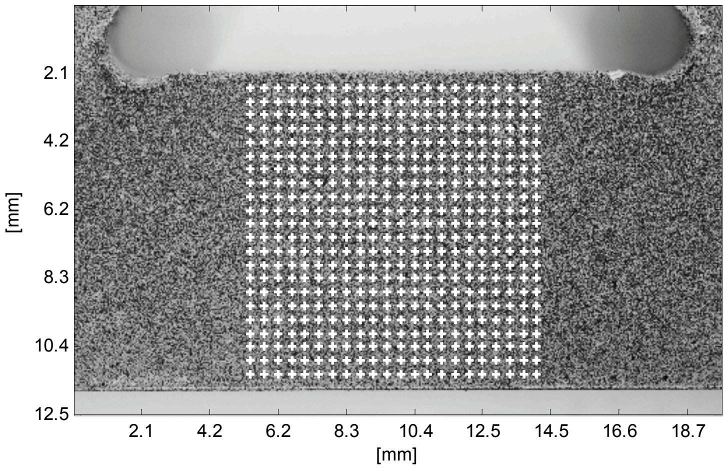


**Fig. 3.** Region of interest (gauge section) and the grid of 22x22 points where the displacement vectors are measured.

Subsequently, the regular orthogonal grid of 22x22 points where the displacement vectors are measured was defined in the reference image, see Figure 3. Each point is the centre of the template of dimensions 61x61 pixels as in Figure 1. The displacement vector field is evaluated using own DIC software. When displacements are known, strain tensor can be evaluated by differentiation. However, for more accuracy evaluation of strain tensor field from measured displacement vector field which tend to be noisy, a smoothing algorithm based on a polynomial function approximation was used. The choice of an appropriete function depends on expected gradients of displacements. In this case, the resulting strains are linear, so the polynomial quadratic function was chosen. In the smoothing algorithm each measured value of displacement component is replaced by a value of approximation function that approximates its vicinity by means of least square.

## 4. Results

Only one strain component $\varepsilon_{xx}$ was investigated here, but the same approach can be employed for the other components also. The resulting contour plots of measured displacement component $u$ and subsequently computed strain component $\varepsilon_{xx}$ are shown in Figure 4 (left).

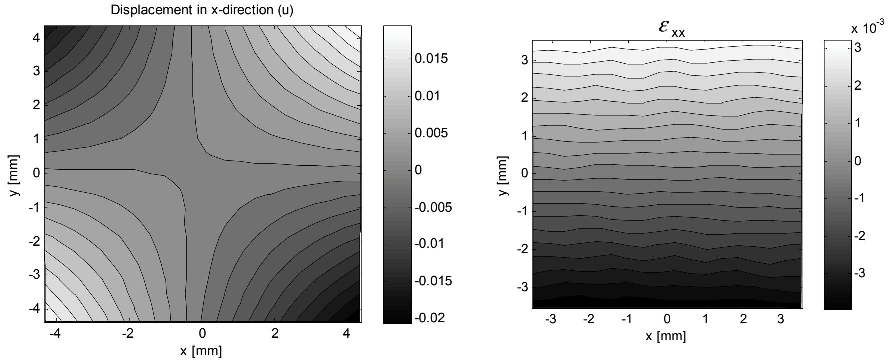


**Fig. 4.** Measured displacement vector component *u*, left, subsequently computed strain tensor component $\varepsilon_{xx}$, right.

For uncertainty determination, the array of differences between measured and analytical strains for each measured value is computed as:

$$D_{\varepsilon_{xx}}(i,j) = \varepsilon_{xx}^{measured}(i,j) - \varepsilon_{xx}^{analytical}(i,j) \tag{2}$$

The standard deviation of these differences serves as desired uncertainty of the DIC experimental system.

$$s = \sqrt{\frac{1}{N}\sum_{i,j}\left(D_{\varepsilon_{xx}}(i,j) - \overline{D}_{\varepsilon_{xx}}\right)^2} \tag{3}$$

The standard deviation was determined as 55.4 µstrain in this calibration. The comparison of measured and analytical strain in a cross-section along vertical axis *y* of the beam is viewed in Figure 5.

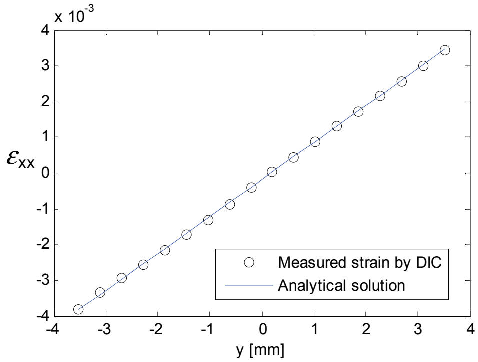


**Fig. 5.** Comparison of analytical solution and measured strain component $\varepsilon_{xx}$ for a cross-section along the y-direction of the beam.

## 5. Conclusion

The optimization of instrumentation and related calibration of experimental system based on DIC method was successfully performed. The uncertainty of the system measurement was determined as ±55.4 μstrain which is a sufficient accuracy for many purposes in experimental practice. It is necessary to point out that the above described optimization is intended for the region of interest of size about (10~50) x (10~50) mm. It was found as very appropriate for strain and stress analysis of crack tip vicinity, for instance. DIC as well as other optical methods is basically dimensionless, therefore at sufficiently different scale, the new optimization and calibration procedure has to be performed.

## Acknowledgement

This work has been supported in part by Research Grant No. 103/09/2101 and Grant no. 103/09/0091 of the Grant Agency of the Czech Republic and by the Ministry of Education, Youth and Sports of the Czech Republic under Research Project AV0Z20710524.

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