Digital Image Correlation in Monitoring Strain Fields Across Historical Tapestries: Tool for Accuracy Assessment

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Abstract. To measure the uncertainty associated with using digital image correlation (DIC) in full-field strain measurement and monitoring in historical art textiles such as tapestries and canvas paintings, a numerical analysis tool has been developed. The tool uses synthetic deformation field generated by finite element analysis to deform digital images of tapestries such that effects of image quality and DIC matching parameters such as subset size, step size and strain filter smoothing size can be investigated prior to the actual experimental tests or to help interpret experimental tests. By varying key DIC parameters such as subset size and strain filter, we concluded that more accurate DIC strain measurement results can be obtained by iteratively varying subset and strain filter size especially at low strain levels when using inherent tapestry surface pattern for deformation tracking until optimal DIC results are obtained. Displacement field accuracy obtained from DIC measurements should not be used for strain accuracy measure.

Introduction

To monitor strains induced under display conditions and self-weight, non-contact measurement techniques are commonly used [1-3) for tapestries. However, fundamental for DIC full-field measurement accuracy is optimal speckle pattern on the test surface for tracking deformation which however cannot be used in tapestries. Conservators rely on the tapestry inherent patterns as the tracking information for DIC measurement. As part of the research effort to investigate the accuracy of DIC measurements for tapestries, a MATLAB based analysis tool was developed at the University of Glasgow to allow quick DIC accuracy and reliability assessment. The tool uses synthetic deformation field generated by finite element analysis to deform reference undeformed digital images of the tapestry and then performs error analysis using the known FEA and the DIC generated deformation fields. The analysis can be performed for different reference image quality which can directly be obtained from different camera settings or artificially altered using MATLAB based image processing tool. Important DIC parameters such as DIC algorithm/correlation criteria, subset size, step size, incremental and direct correlation can be analysed quickly to determine their influence on the DIC measurement. This allows the conservation scientist to be aware of the limitations and suitability of the intended tapestry inherent surface pattern for DIC tracking, determine optimal parameters and distinguish between measurement noise and actual strain values. In this extended abstract, we will present some of the analysis results performed using this tool.

Methodology

Reference undeformed tapestry digital images are incrementally deformed numerically using deformation field generated from finite element analysis. This approach ensures that only systemic error associated with DIC algorithm parameters and the use of tapestry texture for deformation tracking can be quantified. In this case, error from hardware set-up can be eliminated. The FEA generated deformation field is obtained using as input the tapestry dimensions, material properties that reflect the tapestry complex meso-structure, loading conditions (such as length elongation, body weight due to gravity, temperature or humidity variation) and boundary conditions that reflects the tapestry display conditions. The reference image pixel locations are then displaced using the FEA generated deformation field using bicubic interpolation technique. To decouple error due to image texture as tracking information, the DIC measurement always compares the tapestry DIC strains with an ideal speckle pattern digital image numerically generated using Perlin noise technique [2]. Percentage error map between the FEA strain field and the DIC measured strain fields are then used to verify measurement accuracy for a giving image quality and DIC parameters.

Results

As a demonstration, here we used the tool to investigate the sensitivities of DIC algorithm parameters at two different strain levels imposed on a historical tapestry [2] using its surface pattern as DIC tracking information. Also, results obtained using an ideal speckle pattern image [2] are compared with the results obtained with the tapestry image. Linear elastic behaviour was assumed and strain heterogeneity is generated by using Canny edge detection technique [2] to distinguish two different materials in the tapestry. The plots in the Fig. 1 show the high-level strain fields (8%, 39x39 subset size and 15 x 15 strain filter size) while the Fig. 2 (same subset and filter as previous) shows the low-level strain fields. In Fig. 3, large subset (79 x 79) and strain filter size (61 x61) were used to smooth the low strain field shown in the Fig. 2. The percent error maps from the displacement field at the two strain levels are shown in the Fig. 4 while the corresponding error maps from the strain fields are shown in the field 5. It can be observed that using the same DIC parameters for different strain levels produced different strain resolutions with reduced accuracy at low strain level while the displacement field remained unchanged. By increasing the subset size and the strain filter size, the error map in the low strain level is reduced but the heterogeneity is lost as seen in the Fig. 3. At low strain levels, by comparing the DIC results at different subset and strain filter sizes, user can identify areas with high noise level and decide which optimal parameters to achieve reliable DIC results.

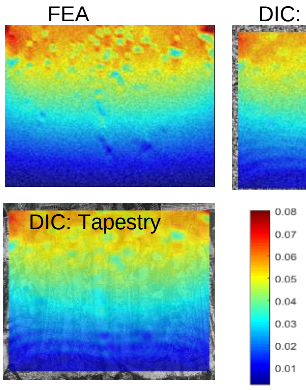

Fig.1. High strain level field.

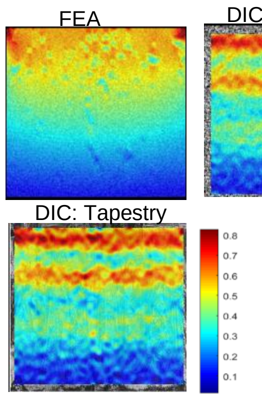

Fig.2. Low strain level field (%).

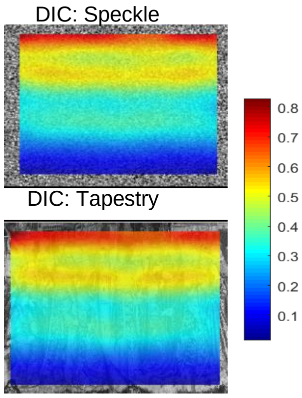

Fig. 3. Smoothed low strain level (%).

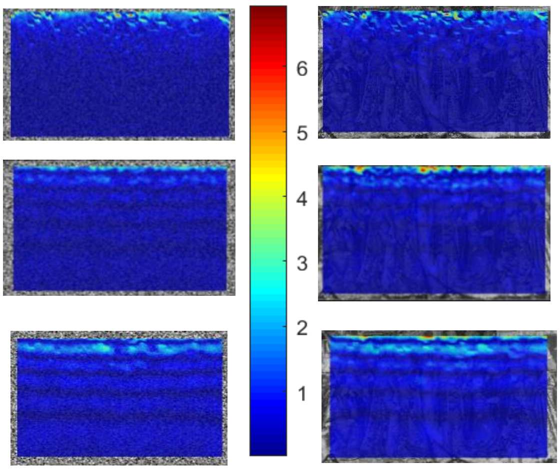

Fig. 4. Displacement field percent error map

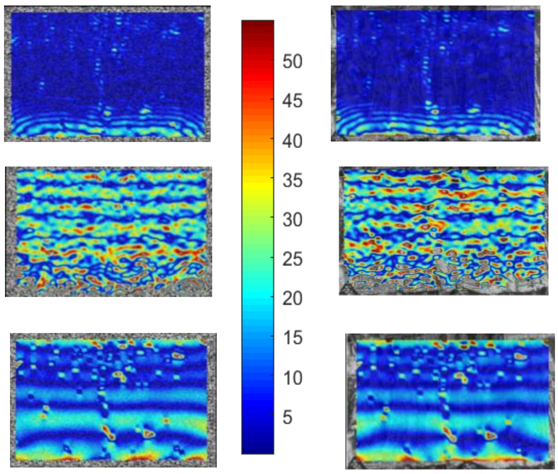

Fig. 5. Strain field percent error map

In Fig. 4 and Fig. 5, the left column is speckle image while right column is tapestry image. Also, the first row is from high strain level, second row is from the low strain level with small subset and strain filter size while last the row is from the smoothed low strain field. In the error maps, values above 55% within the region of interest are not shown. The two strain levels were obtained by varying the assumed areal density [2].

Conclusions

Variation of DIC parameters are less sensitive to DIC computed displacement field but very sensitive to strain calculation especially at low strain levels. This is further worsened when a complex strain field is measured. The techniques developed in this study could be used to ascertain the suitability of tapestry surface pattern for DIC strain measurement, determine optimum DIC parameters for reliable DIC results and decouple measurement noise.

References

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