An adaptive DIC algorithm for measuring small strains in composites

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1. INTRODUCTION

The DIC technique has been widely used to obtain a full deformation field due to its low experimental cost such as simple setup, specimen preparation and low requirements in measurement environment. The traditional approach is a subset based approach, having some important drawbacks, keeping it from being used in some specific domains. The lack of inter-subset continuity increases sensitivity of the local approach against noise, leading to noisy measured displacements. These measurements should be smoothed out prior to differentiation to minimize their effects on the strain. The downside of this method is that the choice of subset, step and strain window influences the spatial resolution and thus makes data very user dependent. For this reason measuring a high gradient strain field with small amplitudes is difficult using subset based DIC. To avoid the non-continuous displacement field, several global approaches were presented. The current implementations of these global approaches all use a fixed degree of freedoms (DOF), ranging from lower (Q4 element) to higher order (24 node elements) meshes. The use of fixed DOF leads to very user/approach dependent results, as natural smoothing is performed. Here, to circumvent this dependency a self-adapting global DIC procedure is proposed. A small introduction to the method is given but the main focus is on the in depth validation presented.

2. CONCEPT

The self-adapting procedure is based on conservation of optical flow. By minimizing the sum of squared differences (1) with respect to the displacement parameters used in the displacement description (2), a linear system (3) is obtained.

$$\epsilon^2 = \iint_{\Omega e} \left(f(\boldsymbol{x}+d) - g(\boldsymbol{x}+d')\right)^2 dx \quad (1) \qquad d = \sum_i \sum_\alpha \Phi_i(\boldsymbol{x}) d_{i\alpha} \quad (2)$$

$$\rightarrow \quad K^S \cdot d = F^S \quad (3)$$

Where f(x) and g(x) are respectively the reference and deformed image, d the displacement described by the shape functions Φ_i (x) and displacement parameters $d_{i\alpha}$. The choice of shape functions define the number of DOF's, and thus the order/polynomial degree of the elements used (e.g. Q4, Q8 elements). By using error/convergence estimators, the algorithm adapt/updates the mesh where needed (e.g. regions with highly heterogeneous deformation) in analogy with adaptive finite element procedures. Updating is analogous to p-refinement in FEA, as each region gets extra DOF (higher order functions) when updated.

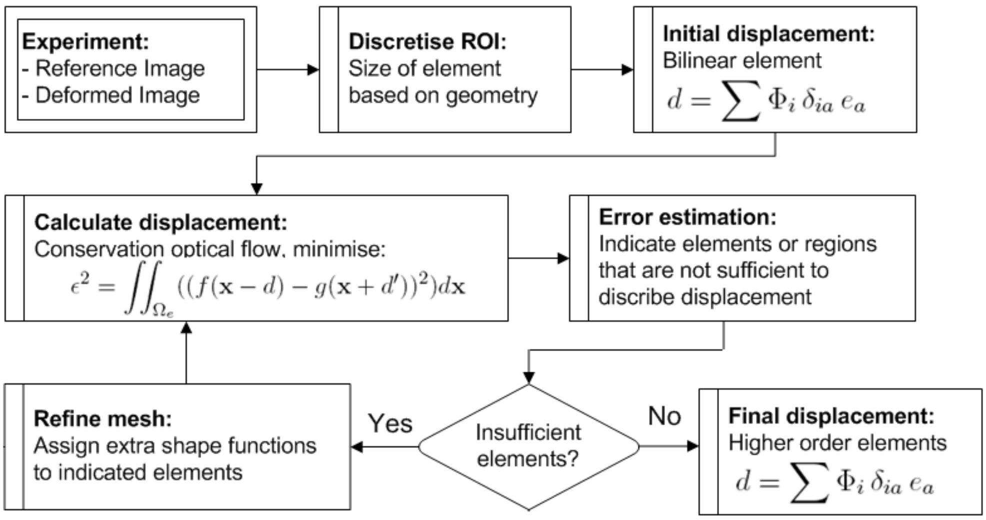

Fig 1: Flowchart of the p–DIC algorithm.

3. VALIDATION

An in-depth comparison of the newly proposed algorithm and the subset based method is performed. Series of sinusoidal deformed images were numerically generated with various frequencies and amplitudes to define the spatial and measurement resolution. Also the performance of the self-adapting feature is validated. For comparison to the subset method, our subset-based platform "MatchID 2D" is used. In the implementation of p-DIC the same libraries for interpolation and mathematical operations as in MatchID are used, leading to a more profound comparison. The resolution is determined by using a so-called self-correlation test, implying the correlation between two images where no deformation is performed but noise is added. The measurand resolution is defined as the global standard deviation of the biased measurand field. The spatial resolution is defined as the lowest period (equals highest frequency) of a sinusoidal deformation the method is able to reproduce before losing a certain percentage of amplitude (= criterion). Using these definitions, a relation between measurand and spatial resolution can be established for several subsets/polynomial orders. The relation is shown in Fig 2 representing a combination of the amplitude loss and displacement resolution in function of the spatial resolution.

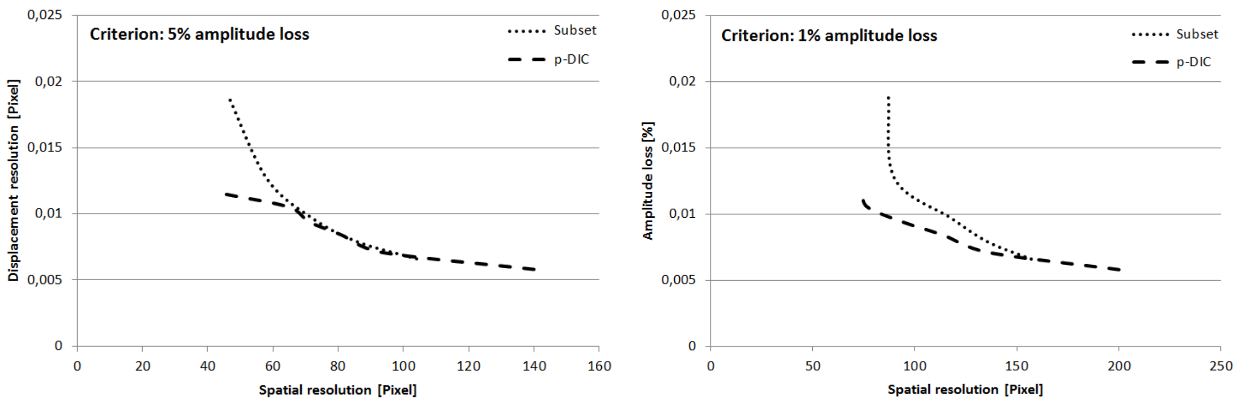

Fig 2: Displacement resolution in funtion of spatial resolution. Criterions 5% and 1%.

First of all, as expected, a decrease in spatial resolution (more heterogeneous deformation) is obtained by using smaller subsets or higher order elements. Related to the decrease in spatial resolution, an increase in resolution (not desired) is observed. Lowering the criterion for spatial resolution (% loss in amplitude, more accuracy) increases the difference between the subset and p-DIC method. At 1% the difference is larger than at 5%. In general it can be concluded that for low heterogeneous displacement measurements (high spatial resolution – Right side in graph) the subset and p-DIC are comparable. For higher heterogeneous displacement measurements (low spatial resolution – Left side in graph), the p-DIC has a lower displacement resolution then the local method.

A Similar procedure is followed for the strains by changing the strain window size/polynomial order. Results are shown in Figure 3.

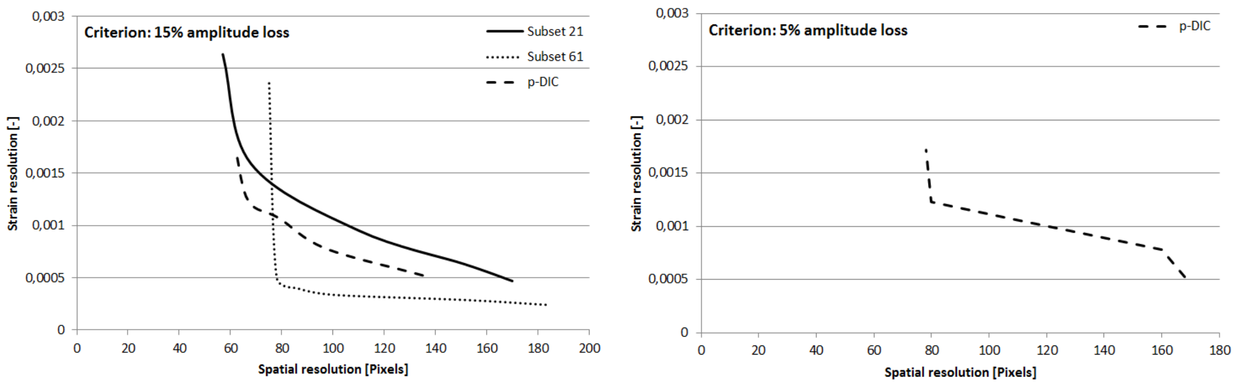

Fig 3: Strain resolution in funtion of spatial resolution. Criterions 15% and 5%.

Similar as in displacements, lowering the criterion for amplitude loss (determining the accuracy) increases the difference between the methods. The local method was not able to reproduce the strain fields with an accuracy of 5%. Increasing this criterion made comparison possible showing that local and global become competitive. The same conclusion can be drawn as in the displacement resolutions, saying that for high accurate low spatial resolutions the p-DIC method clearly outperforms the local method. Note that these results are obtained using ideal parameters. In experiments, these ideal parameters (subset, step, strain window) are not known and choosing others will heavily change the data. The p-DIC method is, due to t

4. CONCLUSION

A new correlation algorithm is presented. The algorithm is based on global digital image correlation and adopts features from the adaptive finite element. The region of interest is described by an adaptive element mesh. A p-refinement scheme is implemented so that the elements in the mesh are capable of rising in degrees of freedom when the error estimators indicate them to do so. Using measurands resolution and spatial resolution, a validation of the traditional local and newly presented p-DIC is performed. Results from the validation indicate that the p-DIC method has a lower measurand resolution for the same spatial resolution compared to the local method. Also from the strain validation can be concluded that for accurately measuring low spatial strain fields the p-DIC method is more favourable then the local method. Beside the advantage in performance at optimal settings, an other big advantage is found. Because of the self-adapting mesh, the method becomes less user dependent. The spatial resolution is, in comparison to the local method, not limit by initial user settings. Future work is mainly aimed at the further development of the error estimators as they are a key in the p-DIC procedure.