Local or global DIC: noise robustness versus spatial resolution

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INTRODUCTION

Digital image correlation is a popular technique used in experimental mechanics to obtain surface deformation fields. The popularity can be clarified by the low experimental cost, easy specimen preparation and low environmental requirements. In the 2D version, the matching between two digital images can be done in a local or global approach. The local approach is based on tracking each pixel separately by its neighboring pixels. As a pixel and its neighboring pixels are usually called a subset, this method is often referred to as the subset method. The main disadvantage of the local method is that pixels are sought individually and thus a non-continuous displacement field is obtained. Alternatively, to counter the non-continuity, the global method was developed. The global method is based on tracking all pixels at once from reference to deformed images by the use of a finite element mesh. The use of a mesh enforces the displacement field to be continuous and thus results are C^0 continuous. It has been shown that for equal element sizes, the estimated variation of displacement for the local method is higher than the variation for the global method [1]. And thus it is stated that the global approach is more robust to noise than the local method. However, robustness against noise must always be treated with an evaluation of the corresponding spatial resolution. Therefore in this work not only the displacement resolution (robustness to noise) is validated, but also the corresponding spatial resolution is investigated to have a more profound comparison between both methods. It is emphasized that both implementations used in the comparison adapt identical algorithms (interpolation, filtering, …) apart from the ones underlying global and local. As such, the comparison can be seen as a true benchmark. For the local method the in-house developed correlation platform MatchID 2D [3] is used, for the global method two approaches are implemented. First a Q8-DIC [4] is used. Here a mesh is constructed where all elements are quadratic. Next a novel p-DIC method is used [5], where elements do not have a fixed order but automatically (user independent) receive higher order shape functions whenever needed to represent the real deformation field. The approach is implemented in the platform “AdaptID”.

METHODOLOGY

Displacement resolution: The resolution of the measured displacement is the smallest change in the displacement to be measured that produces a perceptible change in the measured displacement field. In this sense, the resolution is quantified by the level of noise in the measured displacement. Due to image noise and other influences, a deformation field between two non-deformed images is measured. The displacement resolution is here defined as the global standard deviation of the biased field.

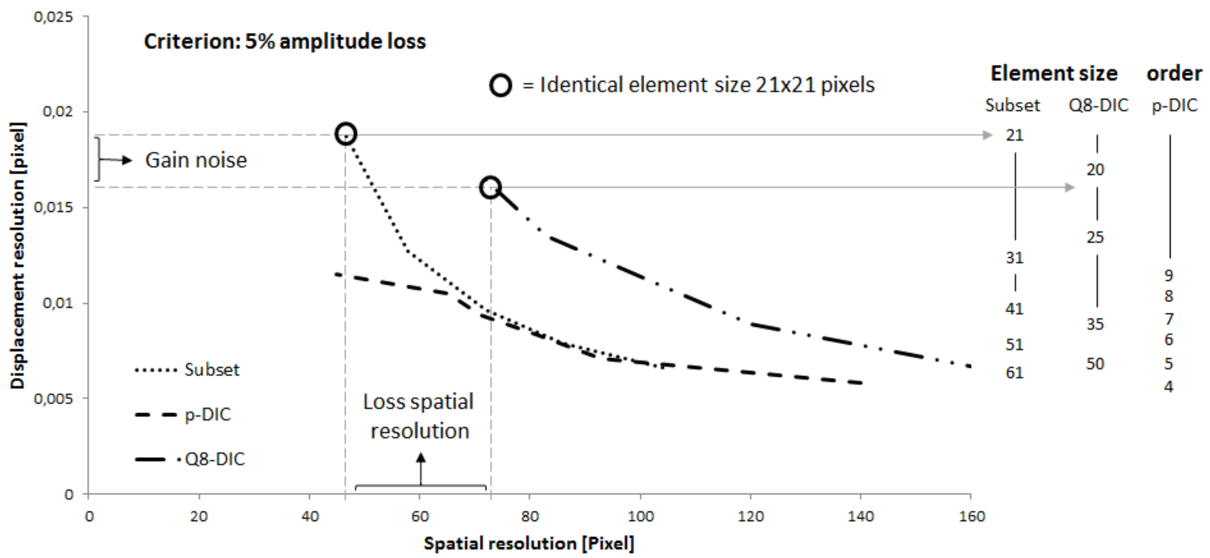
$$resolution = \sqrt{\frac{n\sum_{x,y}[\Delta u(x,y)]^2 - \left[\sum_{x,y}\Delta u(x,y)\right]^2}{n(n-1)}}$$

Spatial resolution: The spatial resolution is generally defined as the smallest distance between two point for which two independent measurements can be obtained (ISO/IEC guide 99, 2007). Or equivalently, the area needed to calculate a quantity. Accordingly, for the local method the spatial resolution corresponds to the subset size itself. The traditional definition however, is not applicable to global DIC as the area needed to correlate a data point is not clearly defined. Here an alternative criterion is used, based on the evaluation of sinusoidal displacement fields [2]. It is proposed to evaluate the spatial resolution by determining the lowest period P (i.e. highest frequency) of a sinusoidal deformation $u(\boldsymbol{x})$ that the method is able to reproduce before the amplitude loss of the reconstructed sine wave (ΔA) equals the permitted threshold α, e.g. 5%.

$$Spatial\ Resolution = P|_{\Delta A=\alpha} \qquad u(\boldsymbol{x}) = \begin{cases} u_x = a\cdot\sin(\frac{2\pi}{P}\cdot x) \\ u_y = 0 \end{cases}$$

LOCAL VERSUS GLOBAL

The robustness to noise and spatial resolution are inevitably bounded to each other. For that reason it is interesting to identify the relationship between both values for both the local and the global method. To improve the robustness to noise for the local method the subset size should increase, for the Q8-DIC method the element size should increase and for the p-DIC method the element order should be reduced. In graph 1, the robustness to noise is varied and the corresponding spatial resolutions are determined.



Graph 1: spatial versus displacement resolution for the subset method, Q8-DIC and p-DIC.

When using the same element size, the noise floor for the Q8-DIC is as expected lower than the subset method for the same element size. The loss in spatial resolution though is reasonably higher for the Q8-DIC approach, which has not been taken into account before. The smoothing nature of the continuous displacement field provides a high robustness to noise, but limits the methods capability of capturing deformations with a low spatial resolution. The p-DIC method however provides also a high robustness to noise due to the continuous displacement field, but is still able to represent low spatial deformation due to its higher order elements.

CONCLUSION

A comparison between local and global DIC algorithms has been presented. Besides the usual noise robustness, the corresponding spatial resolution is taken into account. The noise resolution is defined as the variation of the biased displacement field. The spatial resolution is defined as the period of the sine wave the algorithms are able to reconstruct without losing amplitude due to smoothing effects. It has been shown that the global method is more robust to noise than the local method when element size equals the subset size. For the standard Q8 global DIC though, the corresponding spatial resolution is significantly higher than the subset method due to the smoothing effect of the low polynomial deformation order. For the same spatial resolution, capability of representing low spatial deformations, the subset has a significantly better noise resolution than the Q8-DIC. In this way it is shown that Q8 does not out performs the local method due to the loss of spatial resolution. When expanding the global method to higher polynomial orders (p-DIC), the advantage of noise robustness is preserved due to the continuous displacement field and the higher deformation orders preserve the spatial resolution.

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