Self-adaptive digital volume correlation for accurate internal deformation measurements

Xiang Zou, Bo Wang and Bing Pan[a]

Institute of Solid Mechanics, Beihang University, Beijing 100191, China

[a] Corresponding author: panb@buaa.edu.cn

Abstract. In using subvolume-based local digital volume correlation (DVC) for internal displacement and deformation measurement, subvolume size and shape function are the two critical user-defined parameters, which have significant influences on the accuracy and precision of detected displacements. In general, the subvolume size should be large enough to ensure the unique registration of reference subvolumes in target volume images. Meantime, the defined shape function should precisely depict the underlying local deformation within the subvolume. Regrettably, almost all existing DVC approaches just simply specify fixed subvolume size and shape function for all calculation points based on the user's input. In this talk, we will describe a self-adaptive DVC that can adaptively selection of optimal subvolume size and shape function at each calculation point, thus allowing more accurate internal deformation field measurement, especially for unknown heterogeneous deformation cases. Basic principles and algorithm implementation of self-adaptive DVC is detailed. The accuracy advantage of the presented self-adaptive DVC approach over classic one using fixed subvolume size and shape function is demonstrated through numerically simulated three-point bending tests, real-world indentation tests.

Introduction

In subvolume-based local DVC, subvolume size should be large enough to ensure the unique registration of reference subvolumes in target volume images [1]. Also, the defined shape function should precisely depict the underlying local deformation within the subvolume. It is evident that reference subvolumes with larger sizes generally offer sufficient intensity gradients and therefore better noise suppression effect, and are beneficial to reduce noise-induced random error. However, the local deformation within a large subvolume tends to be more complex, especially in nonuniform deformation cases, which cannot be approximated by the regularly-used first-order shape function with 12 parameters. More seriously, the undermatched shape function would give rise to significant systematic errors in measured displacements. In this case, a 30-parameter second-order shape function that can depict more complex deformation is preferable. However, the optimization of 30 parameters generally results in both higher random error and computation complexity. It is therefore clear that, in practical DVC measurement of unknown deformation fields, optimal subvolume size and the best shape function should be selected adaptively for each calculation point to realize high-accuracy internal full-field deformation measurement. Regrettably, almost all existing DVC approaches just simply specify fixed subvolume size and shape function for all calculation points based on the user's input [2,3]. To improve the measurement accuracy, we propose a self-adaptive DVC approach capable of automatically selecting optimal subvolume size and the best shape function for each calculation point. The accuracy advantage of the proposed self-adaptive DVC (SA-DVC) is demonstrated using numerically simulated three-point bending experiments and real-world indentation tests.

Methods

In SA-DVC, through a V-shaped theoretical error model, the total displacement error at each calculation point can be predicted as a function of subvolume size when using two different (i.e., first- and second-order) shape functions. For instance, Fig. (1) shows the total error in one test using first-order shape function with different subvolume. It can be seen that the total error decreases firstly and then increase with the increase of subvolume size, as "V"-type changes. Hence, there must be an appropriate subvolume size to make the total error minimum. When using second-order shape function, it is similar to this. By minimizing and comparing the total errors using first- and second-order shape function, the best choice of subvolume size and shape function can be identified at each calculation point. More details about SA-DVC can refer [2].

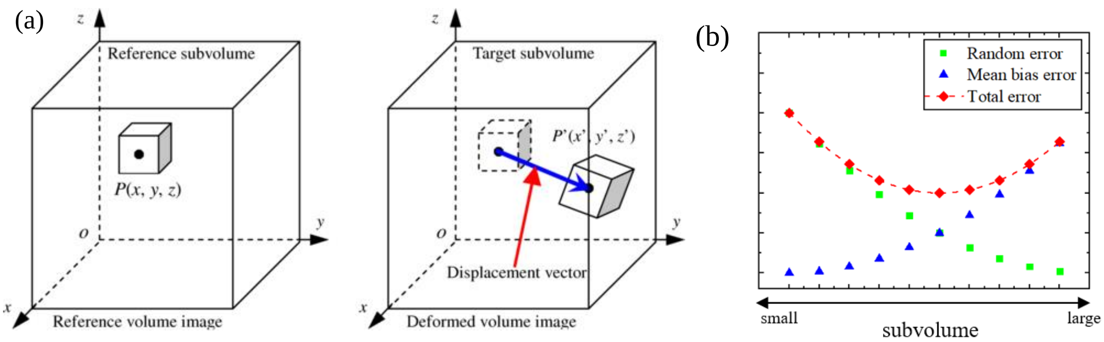

Figure. 1. SA-DVC: (a) schematic figure of DVC, (b) schematic figure of V-shaped total error

Results

To validate the accuracy and efficiency of the proposed method, firstly, a three-point bending test of a spheroidal graphite cast iron sample was numerically simulated. The simulation results show that the SA-DVC has high measurement accuracy. Then, the proposed method is applied to real-world indentation testing. In the experiment, the epoxy resin composite material sample is manufactured with embedded copper particles that act as the internal pattern required for DVC. Fig. (2) gives the results. It can be seen that the general variation trend of measured displacement is consistent with the calculated displacement using Hertz theory. This further illustrates the measurement result is accurate.

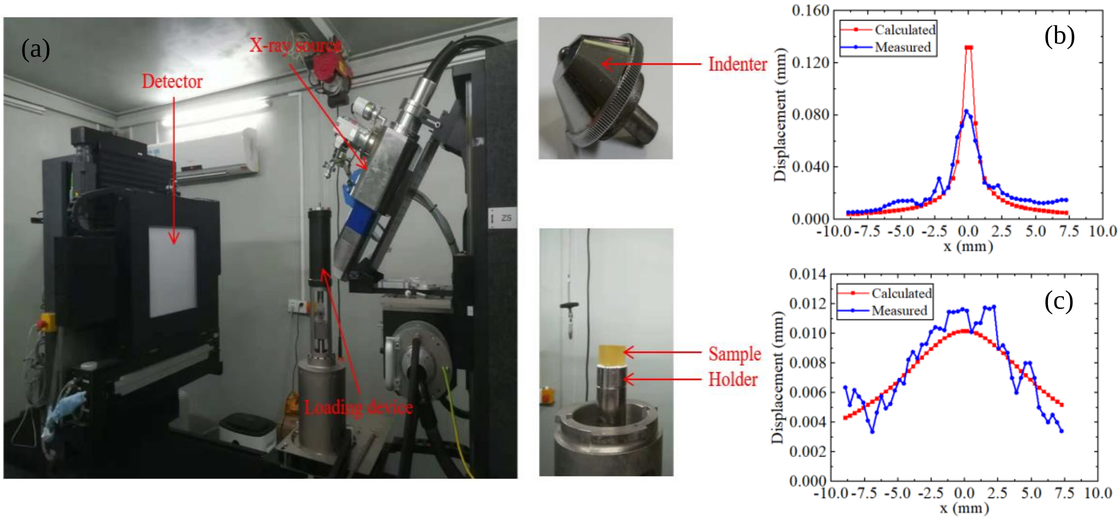

Figure 2. Experiment results: (a) experiment setup, (b) comparison at 0.3 mm load, z = 5.5 voxel, (c) comparison at 0.3 mm load, z = 195.5 voxel

Conclusion

In this work, a self-adaptive DVC approach with a subvolume size and/or shape function optimization scheme is proposed. The accuracy advantages of the proposed self-adaptive DVC over classic ones are demonstrated by analysing numerically simulated three-point bending test and real-world indentation tests.

References

[1] Bouterf A, Jérome Adrien, Maire E, et al: *Identification of the crushing behavior of brittle foam: from indentation to oedometric tests*, J. Mech Phys Solids, Vol. 8 (2017) p 181-200.
[2] Wang B, Pan B: *Self-adaptive digital volume correlation for unknown deformation fields*, Exp Mech, Vol. 59 (2018) p 149-162.
[3] Grédiac M, Pierron F, Avril S, Toussaint E: *The virtual fields method for extracting constitutive parameters from full-field measurements: a review*, Strain, Vol. 42 (2010) p 233-253.