Autonomous surface discontinuity detection method with Digital Image Correlation

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Abstract

Discontinuity detection is an important tool in digital image correlation (DIC) analysis for fracture studies. In this research, an autonomous and robust approach for determining the crack geometry in any surface displacement field obtained by DIC is presented using the Phase Congruency (PC) technique. PC is based on a measure of localized feature significance. A crack geometry construction model is introduced, which uses crack opening displacement (COD) and crack path parameters that are calculated from the displacement field using the PC-based crack detection procedure.

Introduction

Digital Image Correlation (DIC) is a flourishing method in the field of experimental strain measurement because it is full field, easy to set-up, low cost, non-contact and provides high spatial resolution. In the analysis of cracked bodies, DIC allows the calculation of fracture parameters such as crack opening displacement (COD) [1], energy release rate [2], stress intensity factor [3] and J-integral [4].

However, conventional DIC algorithms achieve poor correlation for image subsets close to the crack faces. This is because the subsets used for correlation can only capture continuous deformations from the reference of the deformed image [5]. Also, within the correlation subsets, a crack artefact is presented in the deformed image; hence forcing the DIC algorithm to correlate computationally undesirable pixels of the crack that do not exist in the reference image [6]. Determining the geometry of the discontinuity can allow removal of the crack artefact from the deformed image, which improves the correlation within the subsets close to the crack faces [7]. Domain integral or contour integral methods that are used to calculate parameters such as the *J*-integral are sensitive to the displacements near the crack faces (i.e. the geometry of the crack and particularly the crack tip) as their calculation requires the integral path to start and end on the traction-free crack faces [8]. Therefore the proposed improvement in the DIC analysis will aid calculation of crack parameters such as the *J*-integral.

Most crack detection algorithms apply gradient-based methods to the displacement data to obtain the path of the crack [9, 10]. Such methods rely on thresholding, which is computationally inconsistent and difficult to apply objectively. Gradient-based methods are sensitive to gradient magnitude, smoothness, magnification and do not localize accurately [11]. Also selecting a threshold to determine whether a discontinuity in the displacement field is caused by a crack or simply noise can be computationally problematic. Phase Congruency is a dimensionless quantity that is invariant to contrast and scale [11]. Unlike gradient-based feature detectors, which can only detect step features, PC correctly detects features at *all* phase angles, and not just step features that have a phase angle of 0 or 180°. PC localizes consistently and accurately; this makes it potentially ideal for detecting local discontinuities in displacement fields that are typically the signature of cracks.

In this research, PC is applied to the displacements that are normal to a known discontinuity (*Uy* – coordinate system depicted in Fig. 1a). Applying segmentation to PC indicates localization of the discontinuity, which is removed from the initial displacement field. The upper discontinuity boundary and the lower discontinuity boundary are used to calculate the crack opening displacement (COD). The midpoint between the two boundaries is also used to describe the crack path. The accuracy of PC in detecting the crack path and COD is assessed using synthetically created images for a crack in mode I loading; the images are distorted using displacement fields obtained by finite element (FE) simulations of various crack lengths and CODs. Different levels of zero-mean additive white Gaussian noise were also induced to the synthetic images, before DIC analysis, to simulate the effect on DIC noise and to evaluate PC's de-noising capability. An example of a detected crack is shown in Figure 1.

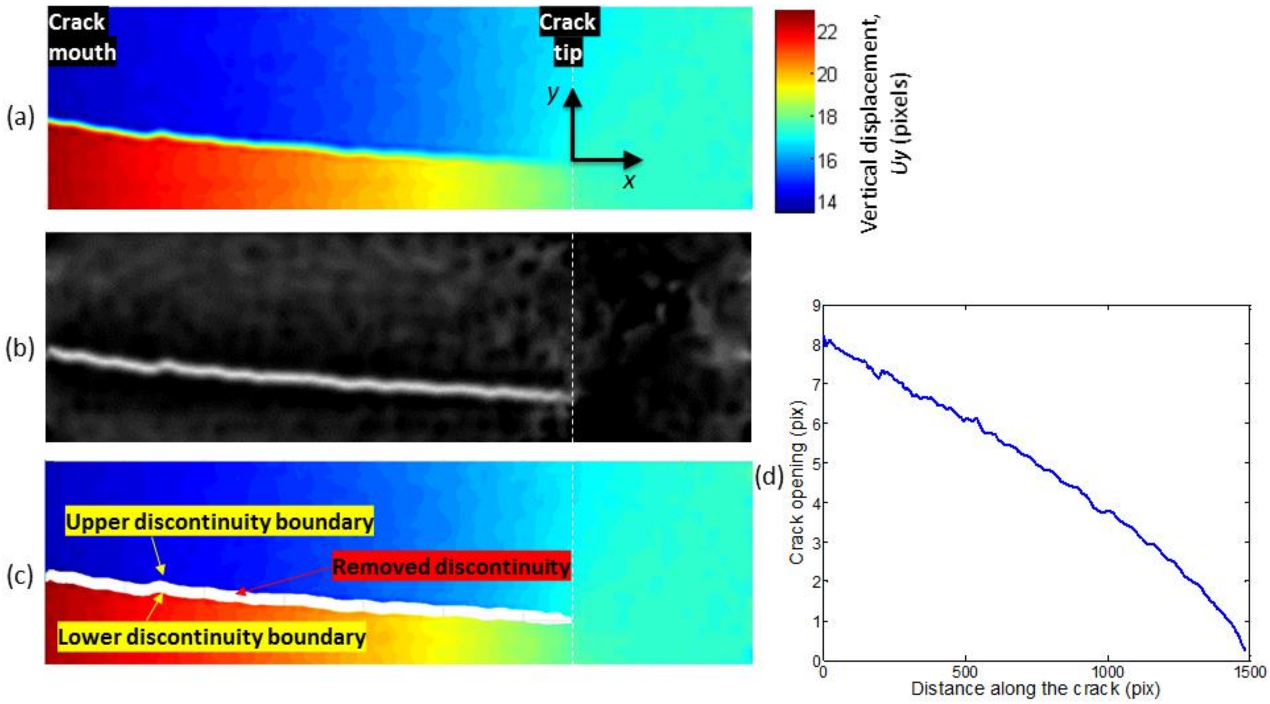

Figure 1 PC based crack detection a) Displacement normal to the discontinuity Uy, b) PC of displacement Uy, c) Segmentation of PC removed from Uy , d) Crack opening displacement

Conclusion

A phase congruency (PC) based crack detection method has been implemented as part of a project to develop a tool for accurate autonomous surface discontinuity detection. The PC method provides the crack path and COD from the DIC displacement field. It has been shown that PC can detect a discontinuity of Crack Mouth Opening Displacement (CMOD) of 0.1 pix with experimentally simulated noise with high order of relative precision.

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