Optics and Lasers in Engineering 96 (2017) 94–106

Contents lists available at ScienceDirect

Optics and Lasers in Engineering

journal homepage: www.elsevier.com/locate/optlaseng

An autonomous surface discontinuity detection and quantification method by digital image correlation and phase congruency

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ARTICLE INFO

Keywords:
Digital image correlation
Fracture mechanics
Crack
Phase congruency
Segmentation

ABSTRACT

Digital image correlation has been routinely used to measure full-field displacements in many areas of solid mechanics, including fracture mechanics. Accurate segmentation of the crack path is needed to study its interaction with the microstructure and stress fields, and studies of crack behaviour, such as the effect of closure or residual stress in fatigue, require data on its opening displacement. Such information can be obtained from any digital image correlation analysis of cracked components, but it collection by manual methods is quite onerous, particularly for massive amounts of data. We introduce the novel application of Phase Congruency to detect and quantify cracks and their opening. Unlike other crack detection techniques, Phase Congruency does not rely on adjustable threshold values that require user interaction, and so allows large datasets to be treated autonomously. The accuracy of the Phase Congruency based algorithm in detecting cracks is evaluated and compared with conventional methods such as Heaviside function fitting. As Phase Congruency is a displacement-based method, it does not suffer from the noise intensification to which gradient-based methods (e.g. strain thresholding) are susceptible. Its application is demonstrated to experimental data for cracks in quasi-brittle (Granitic rock) and ductile (Aluminium alloy) materials.

1. Introduction

Observing the interaction of cracks with the encompassing microstructure of engineering materials is a critical process in structural integrity. Quantitative image-based techniques, such as Digital Image Correlation (DIC), have gained in popularity due to the advances made in the recent years with cheaper CCDs (Charged Coupled Device) and computational power. However, with the advancement of data acquisition, users are faced with the burdensome task of rigorous analysis of large volumes of data, which require user judgement and intervention. The ability to detect and quantify features such as cracks and their associated parameters, such as dimension, from many images is becoming a critical task.

Most approaches to identify cracks in digital images use edge detection methods such as global and local grey-scale intensity thresholding. These require human interaction to be optimal [1,2]. For instance, Ikhlas et al. [3] presented a study of different edge detection techniques including wavelet transform and Fast Fourier Transform (FFT) to identify cracks in bridges, concluding that wavelet transform is more reliable than other methods. However, the method is based on a chosen threshold value, which is a parameter crucial to its performance. Tomoyuki et al. [4] proposed a fast crack detection method, applied to concrete surfaces, that was based on percolation-based image processing; their quantitative analysis showed this to be computationally more efficient that the wavelet approach but at the cost of precision. Additionally, these methods assume that the crack is sufficiently open enough to be detectable in the image. This inherently limits these methods' accuracy to a pixel at best. However, there are image analysis techniques that have sub-pixel accuracy. They track the surface displacement of the features near the discontinuity and therefore can detect cracks that are not otherwise visible in the raw image [5]. For example, Avril et al. [6] introduced a method of detecting surface discontinuities and calculation of the crack width with sub-pixel precision, using a grid that is periodically spaced on the surface of the cracked body and with the aid of Windowed discrete Fourier transform to calculate the phase shift between the cracked faces.

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http://dx.doi.org/10.1016/j.optlaseng.2017.04.010
Received 21 February 2017; Received in revised form 10 April 2017; Accepted 20 April 2017