Towards low-cost condition monitoring for crack detection based on thermal emissions

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Abstract. The advent of packaged bolometer detectors has revived the interest of the experimental mechanics community in quantitative thermoelastic stress analysis (TSA) over the past decade. These packaged bolometers are relatively compact and cost about one-tenth of the price of a standard TSA system, which utilises a high-end photovoltaic effect sensor array. In this work, suitability of an original equipment manufacturer (OEM) microbolometer detector which costs about 1% of the standard TSA system, has been demonstrated for TSA-based in-situ crack monitoring. This technology has the potential to transform the use of infra-red imaging for condition monitoring in the aerospace industry.

Introduction

Thermoelastic stress analysis (TSA) is a well-established, non-contact technique for full-field measurement of surface strains in components under dynamic loading. Despite offering arguably superior strain sensitivity, recognition of TSA has lagged behind other, more widely-used, full-field strain measurement techniques, such as digital image correlation and the grid method. One of the major reasons for this is the high capital cost of the equipment required for TSA. Traditional TSA involves the use of a cooled photovoltaic effect detector, which can cost in excess of £50,000. In the past decade, a few studies have demonstrated the suitability of packaged microbolometer detectors for use in quantitative TSA, which typically cost an order of magnitude less than the cooled photovoltaic effect detectors [1, 2]. More recently, a packaged microbolometer detector has been successfully employed in a TSA-based condition monitoring setup for detection and tracking of fatigue cracks [3]. In this work, the potential of an original equipment manufacturer (OEM) microbolometer detector has been explored for in-situ crack detection and tracking at a cost of about 1% of the price of a traditional TSA system.

Experimental methodology

A rectangular aluminium alloy (2024-T3) specimen of dimensions 102×40×1.6 mm, with a central hole of 6 mm in diameter, was loaded in an Instron universal testing machine at the sinusoidal frequency of 1 Hz with a maximum load of 8.75kN and a load ratio of 0.1. Infra-red (IR) images of the specimen were acquired during this cyclic loading using an OEM microbolometer detector with a sensor size of 160×120 pixels (Lepton 3, FLIR, Wilsonville, OR). The detector was controlled using Raspberry Pi 4, which is a single board computer of dimensions 85×56×17 mm. Nominal strain levels away from the hole edge were measured using a 350Ω resistance strain gauge (RSG), which was bonded on to the specimen. Both the point RSG data and the full-field IR data were simultaneously acquired throughout the duration of fatigue loading.

The acquired RSG and IR data was post-processed in MATLAB to generate un-calibrated TSA maps. These un-calibrated TSA maps basically represent the magnitude of temperature fluctuations caused, predominantly, by the thermoelastic effect. Typically, TSA is performed for full-field quantitative measurement of change in the first strain invariant. However, the focus of this analysis was the automated detection and tracking of fatigue cracks. Hence, in this work, these un-calibrated TSA maps are referred to as Condition Assessment using Thermal Emissions (CATE) maps.

Discussion and Results

Experimental data was processed in batches where each batch consisted of the segment of IR-RSG data, acquired over a duration of 8 seconds. For crack detection, an approach based on orthogonal decomposition was employed. Briefly, CATE maps were decomposed into feature vectors using a pre-defined set of discrete Chebysev kernels. The feature vector uniquely represents the ‘shape’ of a given CATE map and can be considered as a point in the multi-dimensional space. The initiation or propagation of a crack would induce change in the feature vector which, in turn, will cause the point in the multi-dimensional space to move from its original (reference) location. The Euclidean distances between feature vectors representing the CATE maps are plotted against fatigue loading time in Fig. 1. The increase in the Euclidean distance over time provides a clear indication of crack initiation and propagation.

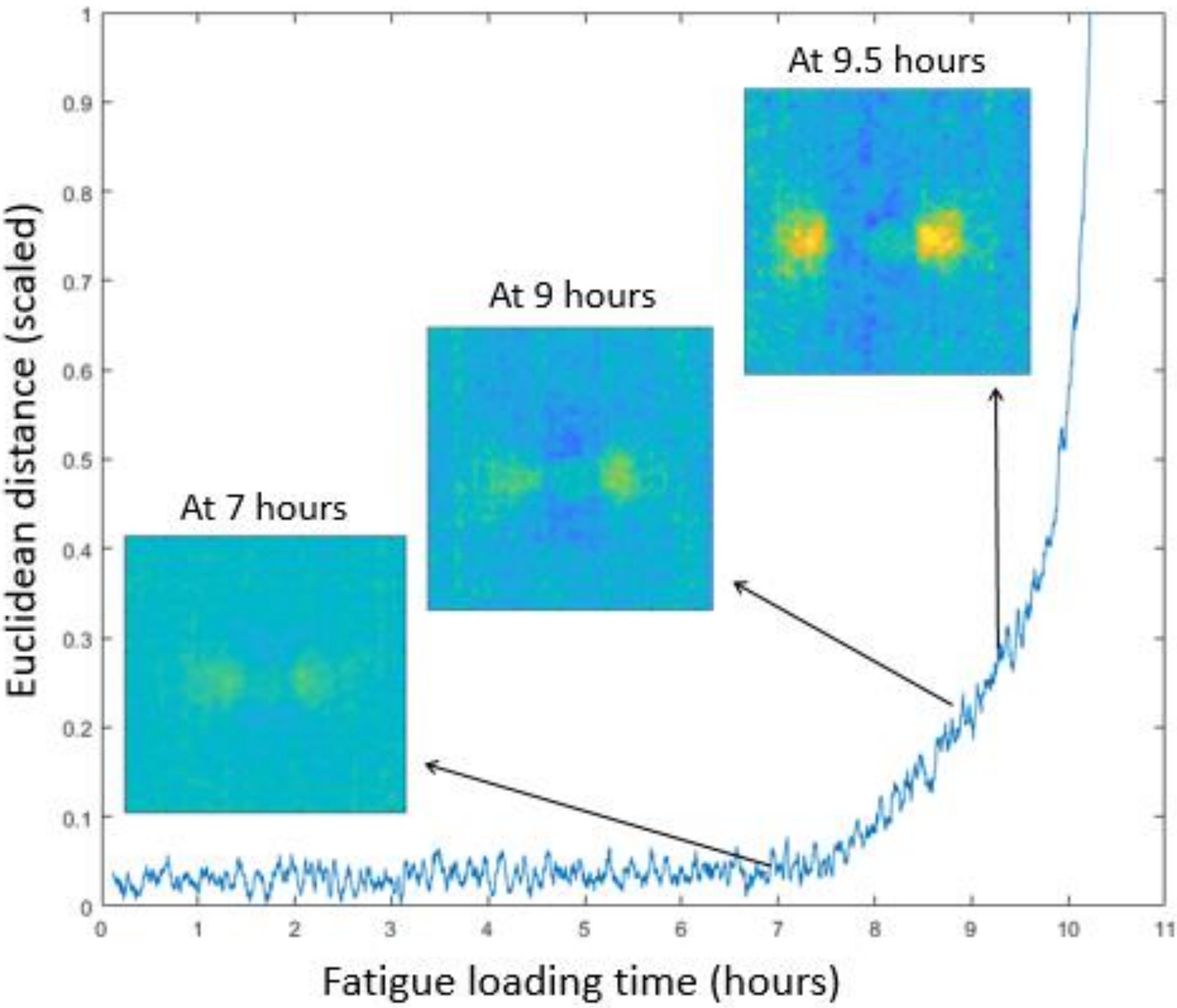

Fig 1: Plot of Euclidean distance between feature vectors representing the CATE maps against time. The insets show the CATE maps at three different instances during the fatigue loading.

Conclusion

This study was carried out to demonstrate the potential of an OEM bolometer detector for TSA-based crack monitoring, which is about 1% of the price of a standard TSA system. Fatigue crack was initiated and propagated in an open-hole aluminium specimen under uniaxial constant amplitude loading. The acquired full-field infra-red data was processed in Matlab to generate un-calibrated TSA (CATE) maps. The CATE maps were orthogonally decomposed into feature vectors and the Euclidean distance between the feature vectors was evaluated to identify both the initiation and propagation of a fatigue crack.

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