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Ensemble Variational Bayes Tensor Factorization for Super Resolution of CFRP Debond Detection

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Abstract: The carbon fiber reinforced polymer (CFRP) is widely used in aircraft and wind turbine blades. The common type of CFRP defect is debond. Optical pulse thermographic nondestructive evaluation (OPTNDE) and relevant thermal feature extraction algorithms are generally used to detect the debond. However, the resolution of detection performance remain as challenges. In this paper, the ensemble variational Bayes tensor factorization has been proposed to conduct super resolution of the debond detection. The algorithm is based on the framework of variational Bayes tensor factorization and it constructs spatial-transient multi-layer mining structure which can significantly enhance the contrast ratio between the defective regions and sound regions. In order to quantitatively evaluate the results, the event based F-score is computed. The different information regions of the extracted thermal patterns are considered as different events and the purpose is to objectively evaluate the detectability for different algorithms. Experimental tests and comparative studies have been conducted to prove the efficacy of the proposed method.

Key words: Optical pulsed thermography, debond defects, CFRP, ensemble variational Bayes tensor factorization, Non-destructive testing.

I. Introduction

The carbon fiber reinforced polymer (CFRP) has become an indispensable structural material in aerospace, boat building and other high-tech fields [1]. Compared with traditional metal materials, the CFRP has many advantages, such as high specific strength, good fatigue resistance and low weight [2]. However, the CFRP exists internal quality issue which can make huge accident and cause great loss. The damage of composite occurs either during the manufacturing process or in-service operations. The types of defects of laminated composite contain delaminations, debond, cracks and impact damage. In order to guarantee the safety, the different non-destructive testing (NDT) methods have been applied.

NDT is an important technology to insure manufacturing quality, repaired quality and increase the in-service life of critical structures [3, 4]. The conventional methods of NDT include ray detection, ultrasonic testing, magnetic particle testing and eddy current testing [5]. In recent years, with the rapid development of thermal imaging equipment, infrared thermography (IRT) based NDT has been used for composite defect detection. It has many promised advantages, such as rapid inspection over a large region, non-contact and high sensitivity. Cramer.K *et. al* [6] proposed an active IRT method for the study of the thermal properties of materials. S.Sfarra and M.Regi [7] inspected the impacted laminates by using IRT technology, such as near-infrared reflectography (NIRR) and transmittography (NIRT) imaging. There are many different external heat sources, such as hot air flow, flash, ultrasonic, and laser [8]. They are used to excite the material for generating a thermal contrast between the feature of interest object and the background. The optical pulsed thermography (OPT) is an attractive NDT technology and has already been widely used for composite. Chulkov *et. al* [9] have tested different optical source for NDT, such as Xenon flash lamps, halogen lamps and LED. Maierhofer Christiane *et. al* [10] proposed the accuracy and limits of flash thermography for CFRP with artificial delaminations and impact damages. The combination of OPT and digital shearography techniques are employed to test the composite material defects for helicopter rotor blade and unmanned aerospace vehicle (UAV) wing sections [11].

Most OPT signal processing methods are limited on the manual selection of the proper contrast components for defect detection. However, the performance is commonly subject to low resolution, blurred edge and mixed noise. In order to