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Toward automatic evaluation of defect detectability in infrared images of composites and honeycomb structures

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HIGHLIGHTS

- SNR maps that account for spatial variation in IRNDT images.
- SNR maps that are independent to a-priori knowledge of defect location.
- Statistical background extraction and analysis in processed images.
- Semi-automatic estimation of segmentation algorithm parameters.

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ABSTRACT

Non-destructive testing (NDT) refers to inspection methods employed to assess a material specimen without impairing its future usefulness. An important type of these methods is infrared (IR) for NDT (IRNDT), which employs the heat emitted by bodies/objects to rapidly and noninvasively inspect wide surfaces and to find specific defects such as delaminations, cracks, voids, and discontinuities in materials. Current advancements in sensor technology for IRNDT generate great amounts of image sequences. These data require further processing to determine the integrity of objects. Processing techniques for IRNDT data implicitly looks for defect visibility enhancement. Commonly, IRNDT community employs signal to noise ratio (SNR) to measure defect visibility. Nonetheless, current applications of SNR are local, thereby overseeing spatial information, and depend on a-priori knowledge of defect's location. In this paper, we present a general framework to assess defect detectability based on SNR maps derived from processed IR images. The joint use of image segmentation procedures along with algorithms for filling regions of interest (ROI) estimates a reference background to compute SNR maps. Our main contributions are: (i) a method to compute SNR maps that takes into account spatial variation and are independent of a-priori knowledge of defect location in the sample, (ii) spatial background analysis in processed images, and (iii) semi-automatic calculation of segmentation algorithm parameters. We test our approach in carbon fiber and honeycomb samples with complex geometries and defects with different sizes and depths.

1. Introduction

Infrared non-destructive testing (IRNDT) has gained great acceptance over the past few years in the NDT community, particularly due to the incorporation of heat-conduction theory and the advances of thermal sensor arrays [1]. Today, thermographic cameras are able to meet a wide variety of demands on temperature and spectral ranges, spatial and temperature resolutions, and acquisition rates [2]. IRNDT community profits considerably from this fact, since well-founded and cutting-edge IRNDT inspections have proven to be reliable and cost-effective for addressing a broad variety of applications [1,2]. For instance, the aerospace and civil engineering industry uses the thermal properties of materials obtained through IRNDT to inspect the structural health of in situ aircraft parts or bridge decks [3–5]. The inspected structures are often exposed to severe operating conditions for which fast and reliable inspection is important.

The advent of new IR sensing technologies has brought not only benefits but challenges as well. Finding and characterizing subsurface flaws is not as time-efficient as one may want, as it relies on trained operators who look for suspicious temperature changes (hot-spots or defective areas) in the thermal images. Moreover, high-contrast objects are not necessarily flaws. For example, a

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material whose density varies spatially may produce temperature artifacts misleadingly recognized as defects. Even though trained operators learn to deal with these kinds of situations, these can become cumbersome (or unmanageable) when plenty of images are to be inspected, which nowadays is common because of the availability of fast acquisition rates and large storage capacities.

To make defect characterization and location more automatic and less subjective, the IRNDT community seeks to create new processing algorithms that along with an optimal experimental setup (as shown in Fig. 2) augment defect detectability i.e. contrast between faulty and flawless areas, and allow automatic distinction between sound areas and those which are defective. In [5], the authors propose an algorithm to detect subsurface defects in concrete bridge decks without prior knowledge of the specimens inner condition. The authors state that their algorithms are able to detect up to 3-inch-depth flaws from processed thermal images, and express their intention to evaluate different heating protocols over the same decks to look for defect detectability enhancement. Another application presented in [6] evaluates the corrosion detection limits in metallic plates and studies the heating protocols, flash and finite-pulse heating, to determine the proper parameters that allow maximum contrasts between corrosion and sound areas. These applications are just a few from the numerous IRNDT applications that intend to enhance and automate defect detectability. Defect detection without human intervention is a pressing demand given the growing amount of thermal data generated by high resolution IR sensors.

IRNDT experiments have in common the explicit goal of selecting the best hardware/software configuration to attain high defect detectability. The accomplishment of this objective requires: (i) the comparison of several processing techniques [7–9], (ii) the assessment of performance of infrared cameras [10], and (iii) the evaluation of heating protocols [11]. Traditionally, IRNDT community employs the signal to noise ratio (SNR) to choose quantitatively the most appropriate configuration. The SNR is computed as the average thermal difference between manually-chosen sound and defective areas, then divided into the standard deviation of the pixels in the sound area. To make the SNR less sensitive to unevenness in the background, the sound area is commonly chosen as an area enclosing the defect.

Even though SNR is widely used in the IRNDT community, it still has shortcomings that need to be solved to make it more reliable. Previous works [8,12,13] identify three major problems in SNR computation that limit its validity. First, SNR computation depends on the sound area definition, which is still an open problem when considering real specimens. Second, SNR has been traditionally used for local evaluation of defect detectability, which means that some prior knowledge of defects positions is necessary. These locations are not available in real specimens. Third, uneven uniform heating and structural noise related to the energy source and the inherent features of a material (absorptivity–emissivity variations), respectively, greatly affect the SNR reliability in that high thermal contrast may be a consequence of temperature differences not only between sound and defective zones, but also between two sound areas.

In our previous work [8], we presented a global approach to decrease the effects of uneven heating by using a flawless area for each particular defect that is exposed to the same radiant energy of that defect. This approach computes a sound-thermal image by filtering out the background tendency of thermal image using a median filter and then estimating the noise level using profiles along sound areas. Despite the benefits of this approach, it requires prior knowledge about the location and size of the defects.

This paper proposes a general framework to estimate image background and generate global SNR maps that do not depend on a priori knowledge of the location of the defects in processed image sequences. Our main contributions are: first, a novel method to calculate SNR maps that takes into account spatial variation and true background, and is independent of a priori knowledge of defect location. Second, a comprehensive analysis of background and defect visibility in processed thermal images. Third, an adaptive method for *hr* estimation in mean-shift segmentation algorithm. Fourth, a study of mean-shift segmentation sensitivity with respect to *hr* and *hs* parameter variation. We test our approach in two image sequences obtained from IRNDT tests on carbon fiber and honeycomb samples. These materials are widely used in aircraft industry [14]. The correct inspection of this type of materials is challenging, given their anisotropy, density variation, and geometric shapes. We believe that this work contributes to the automation of online quality and process control in IRNDT. The rest of this paper is organized as follows. Section 1 describes the methodology. Section 3 presents the theoretical framework. Section 4 analyses and discusses the results. Section 5 concludes this paper.

2. Methodology

This section describes the methodology followed to address the aforesaid issues in IRNDT. The outcome of these stages is an objective method to compute SNR maps and judge the capacity of processing techniques to reveal defects. Fig. 1 presents this

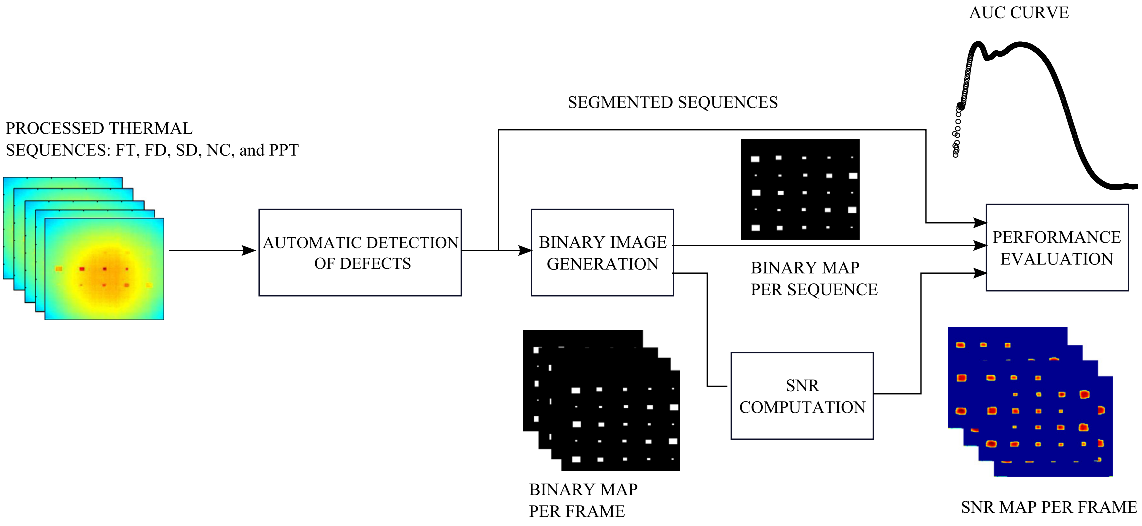

Fig. 1. Methodology to evaluate defect detectability.