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Non-destructive inspection of aircraft composite materials using triple IR imaging

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Abstract: The wide use of composite materials in a number of industrial sectors has necessitated the development of new nondestructive inspection techniques for both manufacturing quality assurance and in-service damage testing. This paper discusses the development of a new holistic inspection system for aircraft composite materials that is composed of three thermographic cameras (operating at different wavelengths such as Near-infrared, Mid-Wave and Long-Wave) placed on the head of a robotic arm. Different setups were investigated in order to achieve optimal settings for a variety of influencing parameters including camera distance from the surface under investigation, excitation source type and power. Experiments were also conducted to define the effectiveness of each thermographic camera towards a variety of defect types. Advanced image processing algorithms were further developed and deployed to enhance the inspection capabilities of the three cameras and improve the interpretation of the collected thermal images. Future work on validating fusion and machine learning tools, their integration as well as on-site inspections has been planned.

Keywords: composites, thermography, aircraft inspection, NDT, data processing

1. INTRODUCTION

Aircraft components suffer tremendous amounts of tension and stress. The integrity of such a complex piece of machinery can be easily compromised by minor flaws that can lead to catastrophic events. Composites (carbon-fiber & glass-fiber) are a big part of an aircraft's shuttle, however the aviation community is filled with conflicting or incorrect information about their safety and capability. The behaviour of the composite structures is very different under normal loads compared to equivalent metal structures. It has been proven through trials, that compared to metals, composite repair patches present less fatigue and corrosion. Undetected subsurface damage can go undetected for long periods and it can result in sudden catastrophic failures. Therefore, there is extreme importance in a truly innovative inspection process capable of identifying the condition of these materials.

A large amount of work has been carried out to develop methods and systems for detecting manufacturing defects, fatigue cracking, structural discontinuities, accidental damage, build damage and environmental degradation in composites. However, despite the existence of traditional NDT methods in aerospace applications such as those used for the inspection of metallic materials, in several instances they are unsuited for the inspection of composite structures. NDT engineers are still restricted to manually driven technology that is unrepeatable and subjective; being prohibited from employing new techniques that are quantifiable, robust, repeatable and reproducible until research provides solid evidence of solutions to these problems. This clearly emphasizes the need for a wider range of faster more accurate NDT techniques to meet the current and future inspection requirements that underwrite structural integrity of composites and composite structures.

1.1 IR inspection of aircraft composites

Transient thermal Thermography and Near Infrared Imaging (Clemente Ibarra-Castanedo, 2012) are prompt and reliable techniques applied for the assessment of composites and composite components that find use in aircraft transport applications. An external source of energy is required in Transient IR Thermography NDT in order to induce a temperature difference between defective and non-defective areas in the specimen under examination. Energy sources can be divided in three categories: (i) Optical excitation, where the energy is delivered to the surface by means of optical devices and the light is transformed to heat. (ii) Halogen lamps (for periodic heating) utilizing thermal waves that propagate by conduction through the specimen. The waves reach a discontinuity that act as a resistance and are reflected back to the surface. (iii) Finally, mechanical excitation that heats up the defects internally with mechanical oscillations. There are two classical active thermographic methods: lock-in thermography and pulsed thermography which are applied externally. These techniques and their applications have both different experimental and theoretical aspects. Thermal maps i.e. thermograms are generated by IR thermography, operating in the mid-wave (MWIR) (3-5 μm) and long-wave (LWIR) (7.5-14μm) portions of the infrared spectrum, and they are the result of thermal emissions from the specimen surface. IR thermography is gaining popularity in many areas

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such as aerospace where large surfaces need to be inspected in situ in a fast and safe manner.

In the case of transparent and semi-transparent materials such as GFRP, near infrared (NIR) vision constitutes an interesting alternative (Clemente Ibarra-Castanedo, 2012). The reflected or transmitted (non-thermal) radiation is recovered from or through the specimen in the near portion of the infrared spectrum (0.9-2.5 μm) with Near Infrared Imaging (NIR). Transmittance and reflectance techniques can be used to perform NIR imaging of transparent structures. In the transmittance technique NIR light passes through the thickness of the panel for the detection of various defects on the surface as well as inside the panel. Using the reflectance technique surface profiling can be performed and the defects' depth inside composite samples can be approximated. A variety of sources can be employed as an excitation source including LED, halogen lamps or even lasers.

A holistic, automated and non-invasive imaging NDT system is presented in this paper for qualitative and quantitative inspection of composites used in aircraft applications. A poly-articulated robotic arm is utilized to allow fast and reliable testing on composite surfaces while the sensors on its head: (i) perform IR Thermography and Near Infrared Imaging NDT scanning, (ii) create the appropriate scanning conditions (material energy excitation) and (iii) ensure precision and tracking of scanning process. Advanced signal processing functionalities have been also introduced, increasing the inspection capabilities of the system. The delivery of automatic and real quantitative information is expected to form new validated testing prototype procedures that will reduce and/or eliminate the unnecessary and subjective inspections and improve the damage evaluation accuracy.

The rest of the paper is organized as follows. Section 2 presents the specifications of the proposed integrated system. The experimental methodology employed here is presented in section 3 and indicative results are given in section 4. Finally, conclusions and future plans are given in the last section.

2. INSPECTION SYSTEM SPECIFICATIONS

The proposed integrated inspection system comprises the following components:

- a poly-articulated robotic arm that enables seamless and accurate operations
- two IR cameras operating at different wavelengths (Mid-wave and Long-wave, respectively)
- one NIR camera operating at the near infrared
- two halogen lamps for heat excitation and
- additional safety equipment including laser sensors and a HD camera.

Detailed information regarding the system's components are given in the following subsections:

2.1 Robotic arm

A KUKA robotic arm was used for its durability and flexibility. Specifically, the KR 125/2 was utilized which is a high payload masterful mover with a fist-shaped work envelope, and is ideal for the implementation of cost-effective, space-saving system concepts.

2.2 Imaging equipment

The Bassler acA1300-60gm camera was selected for NIR thermography (NIR cameras, n.d.). It is a small-sized camera with 1.3MP resolution, 60fps acquisition rate and wavelength sensitivity of 700-1.300nm that fits our needs for the GFRP composites.

Figure 1: The Bassler NIR camera and the Fujinon lens used for the experiments

The Infratec ImageIR 5300 IR camera was utilized for Mid-wave inspection of composites with a geometric resolution of 320x256 pixels, thermal resolution of <0.015K at 30°C and a spectral range of 7.5–14μm. For the inspection at the long-wave range, the Infratec VarioCAM hr head 600 camera was employed with a geometric resolution of 640x480 pixels, thermal resolution of <0.03K at 30°C and a spectral range of 7.5–14μm. Figure 2 shows the aforementioned cameras.

(a) (b)

Figure 2: The ImageIR 5300 (a) and the VarioCAM hr head 600 (b) that were used in the experiments

2.3 Excitation sources

A variety of different excitation sources were used in our experimentation. Two HEDLER H25S halogen lamps with total power of 5kW were finally selected for the active thermography measurements. The following excitation sources were used for the NIR measurements: four PANALIGHT halogen lamps with 0.5kW power each, two HOKITA LED lamps with 0.1kW power each and a RADIUM fluorescent circular light with 0.4kW power each.

Figure 3: The Hedler IR excitation source used in the IR experiments