THERMOGRAPHIC NON-DESTRUCTIVE INSPECTIONS OF WIND TURBINE BLADES USING UNMANNED AERIAL SYSTEMS

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Abstract

Wind turbines are gaining importance in the last years because of their high efficiency during energy production without greenhouse gas emission. Furthermore, they can be installed both on and off-shore. However, wind blades maintenance operations have become difficult and expensive due to basically size aspects as well as operative costs related with their location and out-off service period.

A non-destructive technique capable of detecting most significant in-service defects in composite wind blade is Infrared Thermography (IRT). However, this method can only be applied by developing cost efficient in-situ inspection strategies.

This work, presents a feasibility study for defect detection during maintenance operations in wind blades using Unmanned Aerial Systems (UASs). IRT inspections are performed by means of passive IRT methodology, first (i) in specimen located at ground level with artificial defects (as delamination, cracks, impact damage and debondings), and later (ii) during flight operation using an UAS rotorcraft. The developed inspection strategies, inspection results as well as several features of the acquisition system are reported.

1. Introduction

With the increasing number of installed wind turbines and major failures of critical components, the more and more necessity of in-service inspections cannot be neglected. Maintenance for turbines and wind blades are currently based on manual and visual inspections. Onsite inspections are commonly carried out by using rope access technicians or special working platforms which means large time consuming inspections and high human risk [1, 2]. In both cases, the results of the inspections depend on the technicians' ability to spot damage with naked eye. There is an important need for alternative method that allows performing these inspections quicker and more effectively, like contactless Non-Destructive Testing (NDT) methods.

Active Infrared Thermography (IRT) is a NDT technique that has proven to be a useful tool for detecting damage in composites materials such as delaminations, cracks, impact damage, debonding, entrapped water [3, 4], etc. Passive IRT can also be used to perform blade on site inspections without external heating source (e.g. halogen lamps). In order to maximize the detection of defects during passive inspections, climatic changes on-site or heat differences produced by illumination aspect in the blades can be utilized [5]: On site temperatures from night to day could varied strongly (producing thermal effects on blades), and energy abortion in illuminated areas can be utilized to produce a heat flow in the elements.

This study presents a thermographic study for the inspection of wind blades using UAS rotor platform. Both, feasibility testing campaign for detecting typical blade defectology by IRT and concept demonstration using UAS system operation in autonomous way have been performed. First, artificial defects have been introduced in the rotor blade to establish the detectability limits of the passive IRT. Once parameters such as IR camera-blade optimal distance, wheather conditions, etc. were set, a flight campaign using UAS rotorcraft with IRT camera was designed and executed to define operational mode and automated flight strategies.

2. Feasibility NDT ground campaign

A testing campaign has been performed using wind blade “on-ground” at Jerez, Spain. The dimensions of the inspected element were 44 and 2 m long and root wide, respectively. The blade structure is composed by laminated fiber glass, balsa wood and gel coat.

Artificial defects have been introduced into the element in order to establish the detectability of the most common defects appearing during service such as cracks, delaminations and impacts (Figure 1).

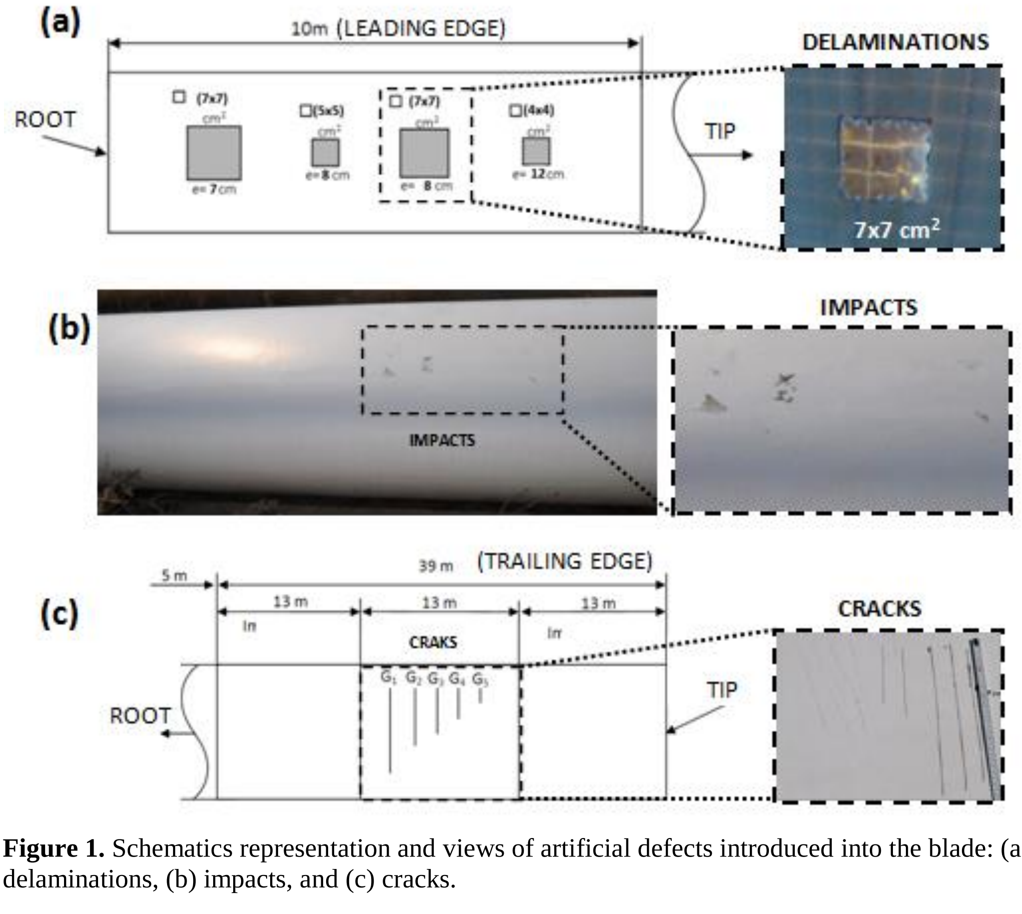


Figure 1. Schematics representation and views of artificial defects introduced into the blade: (a) delaminations, (b) impacts, and (c) cracks.

Inner blade material has been removed in the leading edge in order to simulate a 70x70 mm^2 delamination with 80 mm thickness (Fig. 1.a). Elements with different weights (from 1 to 5 kg) were used to simulate impact damage in the leading edge with different grade of severity (Fig. 1.b). Cracks from 0.55 to 1.25 mm thickness have been manufactured on the trailing edge as well using cutting discs (Fig. 1.c).

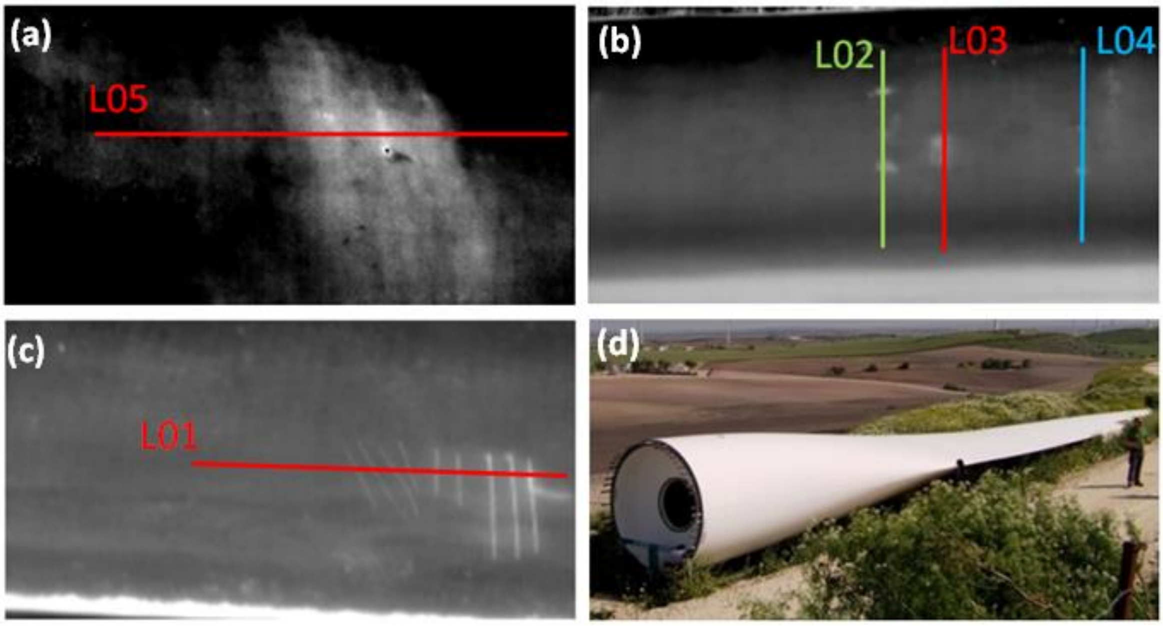


Figure 2. Thermographs with indication of artificial defects: (a) delaminations, (b) impacts and (c) cracks; (d) View of inspected "on-ground" blade.

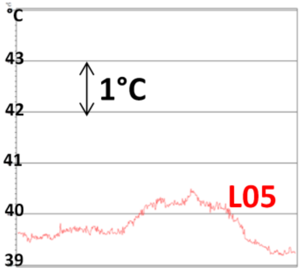
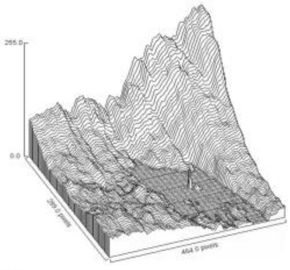
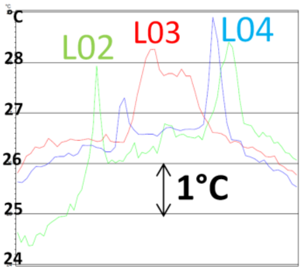
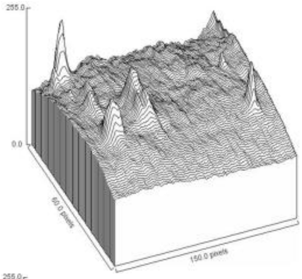
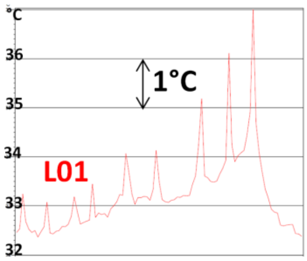
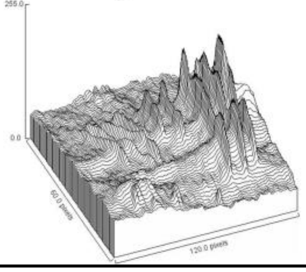
Linear Analysis	Planar Analysis	Description
		Delamination: Removed inner blade material (area= 35x35 mm^2, thikness= 80 mm) Max. contrast: 0.5°C
		Impacts from weights ranging from 1 to 5 kg Max. contrast: 1-2°C
		Cracks from 0.55 to 1.25 mm thickness Max. contrast: 1-3°C

Table 1. Linear and plane thermographic analyses.

During thermographic inspections, the optimal testing parameters and environmental conditions have been defined. The recorded IRT images (Figure 2) has been registered using passive thermography, taking in advantage the temperature ambient changes induced in the element during the day. Thermographic results have shown 100% detectability of the 70x70 mm delamination, impacts and the artificial cracks (Figure 2.a, b and c, respectively).

In order to improve the ability of the operator for defect detection, different software processing methodologies have been investigated. Linear and planar analyses (Table 1) were carried out in all thermographs in order to establish the temperature variation caused by the artificial defects. Linear analysis (Table 1) show how the delamination introduce 0.5°C in the thermal pattern (L05), impacts introduce from 1°C to 2°C (L02-L04), and cracks from 1°C to 3°C (L01). Planar analyses show a 3D representation of each thermogram, making easier the interpretation of the results.

3. Flying paths

For this application, an all-electric helicopter has been selected (Figure 3.a) with maximum payload of 8 kg, equipped with advanced autopilot system (Flying Cam) and a ground station for its control. A high performance infrared camera (FLIR 650) has been embarked in the UAS to perform the thermographic inspections. The flight strategy is designed to achieve the entire blade inspection using a single battery (with flight duration of 18 minutes).

To obtain an adequate image resolution and to keep a safe operation area for the UAS, a distance of about 5 meters from the wind turbine blade and displacement speed of 1m/s were defined. The inspection strategy (Figure 3.b) was defined as follow: (i) UAS positioning at the root's blade; (ii) bottom-up inspection of leading edge; (iii) 90 degrees rotation and positioning on the upper shell; (iv) up-bottom inspection; (v) 90 degrees rotation and positioning in the trailing edge; (vi) bottom-up inspection; (vii) 90 degrees rotation and positioning in the lower shell; (viii) up-bottom inspection, and (ix) homing of the system.
In this way, the inspection time has been reduced since no mechanical rotation of the blade is required.

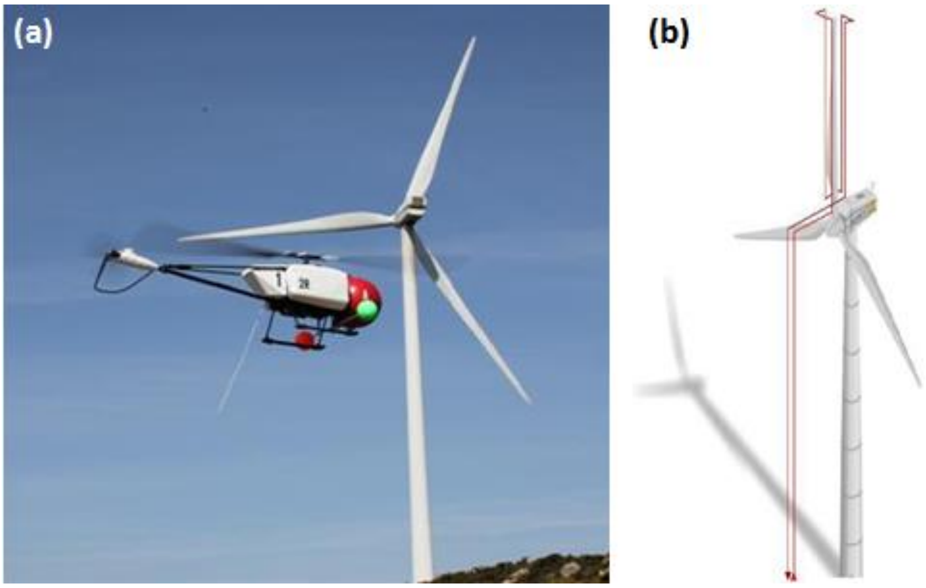


Figure 3. (a) View of UAS (SAHARA) and (b) trajectories for flight inspections.

4. NDT flying inspections

After establishing the feasibility of the technique for detecting common damage in wind blades, an IR imaging & processing unit for in flight operation has been developed, as well as operation and flight strategies.

The first thermographic flight campaign was conducted in Tarifa, Spain, using wind turbine of 10 m blade length and pitch brake system at the tip. The distance between the UAV and the blade was set at 5 m and the flight duration was approximately 15 minutes.
Figure 4 shows changes in the thermal pattern produced by the internal structure and other external sources: (A) pitch brake system, (B) bonds between upper and lower shell, (C) access gate and (D) surface roughness.

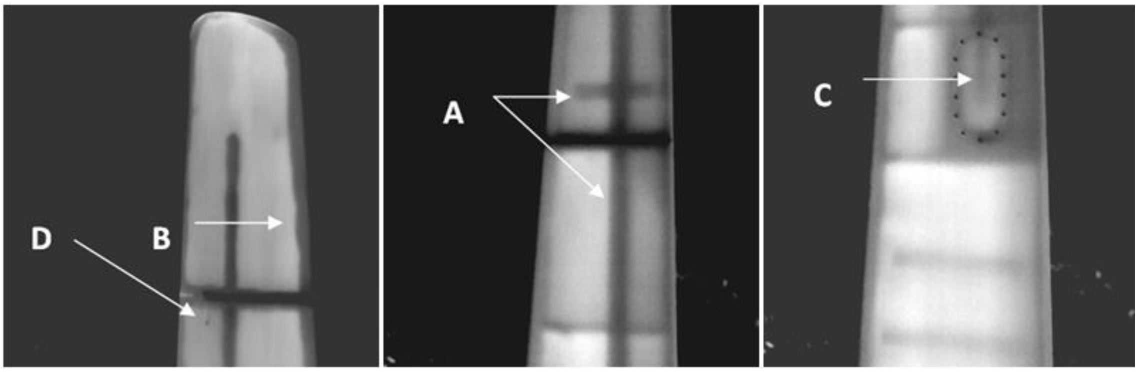


Figure 4. Thermographic in-flight results of the inspection conducted in 10m blade in Tarifa, Spain.

The results obtained after 2nd flight testing campaign are presented in Figure 5. In this case, a much larger wind turbine located in Granada, Spain, was selected. Due to the blade size (40 m long) the distance between the blade and the UAS has been set in 10 m. The results show variations in the thermal pattern caused mainly by: (E) bonds between shells and beam, (B) bonds between upper and lower shell, (F) balsa wood and (G) indications of unknown provenance.

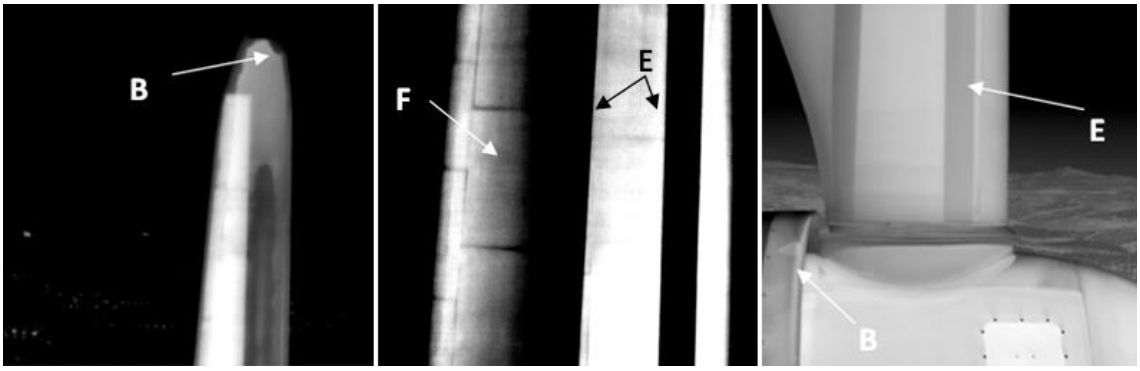


Figure 5. Thermographic in-flight results of the inspection conducted in 40m blade in Granada, Spain.

5. Conclusions

The feasibility of the proposed inspection methodology has been demonstrated for detecting the most common wind blade service defects such as cracks, delaminations and impacts, by using passive infrared thermography.

Studies carried on during flight operations have revealed the potential of the aerial surveys, detecting in these cases relevant structural indications, in short time inspections (15-20 minutes / blade). Flights have been performed in autopilot mode, avoiding operational risk coming from manned control. In flight software has been developed for on-line image processing, resulting in very useful tool for rapid decision taking.

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