Hyperspetcral Imaging for Erosion Detection in Wind Turbine Blades

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I. Introduction

Inspection of wind turbine blades is required to identify any defects or failures and decide on any remedial actions e.g. blade repair or replacement. Traditionally, inspections have been performed by rope access technicians who visually inspect the blades and record damage using standard photographic equipment.

Recent developments have seen an increase in popularity in the use of remote based inspection techniques using ground mounted cameras and cameras installed on Remotely Operated Aerial Vehicles, more commonly referred to as drones. Whilst these techniques remove the need for human access to the blades, imaging is performed remotely and does not always provide adequate image quality using standard high definition cameras. As a result, there is a growing interest in imaging techniques based on other regions of the electromagnetic spectrum. Laboratory and field based trials are required to properly examine this potential and understand which frequencies can be applied to imaging blades.

This paper demonstrates a Hyperspectral Imaging technique in its application to imaging surface defects on a section of wind turbine blade in a laboratory.

II. Wind Turbine Blades

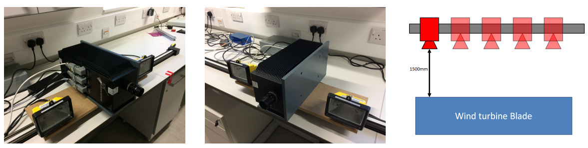
The materials of blades must be strong and stiff, yet as light as possible to satisfy the blade design criteria and to minimise both the weight induced fatigue loads and the loads on the tower and foundations. The materials of contemporary blades are usually fibre-reinforced composites which provide low weight, high strength and stiffness and optimal performance in fatigue. The majority of blades are made of glass fibre/epoxy, glass fibre/polyester or carbon fibre/epoxy composites [1].

Blades are generally designed to last for a minimum of 20 years, during which time they will be subjected to varying weather patterns and wind loads that become more extreme in the hostile marine environment. Thus, they should be designed to withstand different types of damage e.g. fatigue damage, erosion and damage due to extreme conditions [2].

Damage can occur in a number of ways. It is important to properly identify different damage types so that appropriate remediation actions can be performed. Leading edge erosion is one of the biggest issues during the operations and maintenance phase of wind farms, particularly offshore. It occurs as a result of different interactions between the blades rotating at high speeds and the environment e.g. icing, strong winds and impact with rain, hailstones, salt spray, dust and other atmospheric contaminants [3].

III. Methodology

A. Equipment Set-up



(a) (b) (c)

Figure 1: Hyperspectral camera set-up

The initial stage of the process was to set-up the hyperspectral camera as follows, see Figure 1. In the lab it is possible to image the blade at a distance that would not be safe to operate at in practice without risking damage to the system or turbine blade. Therefore a distance of 1.5 metres was selected as a good distance to provide adequate resolution of the blade from the camera but yet would still be possible to operate at in the field.

B. Initial Imaging

The blade and camera were positioned and the speed was selected to provide square pixels. Prior to hyperspectral imaging, some images were taken with an RGB camera to provide details of any defects already present within the blade. Following this the first image was taken using the hyperspectral camera, any pre-existing defects were highlighted in this new hyperspectral image, see

Figure 2. For this example the 1300nm band of the image was used, this was selected as it provided the most contrast for each of the damage types.

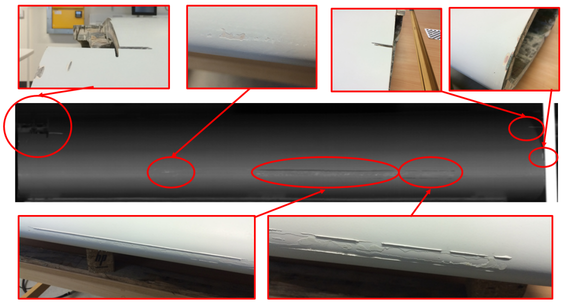


Figure 2: Initial HS image (1300nm band) with defects highlighted

C. Introduction of Damage Types

Having completed the initial study some realistic defects were added to the blade. Those selected were of the type that would be present in a turbine operating in the real world over several years [3], see Figure 3. Each of these damage types provide a different challenge for detection.

(a) Light Erosion (b) Erosion to pink laminate (c) Erosion to grey laminate

Figure 3: Damage Types

IV. Results

A. Band Selection

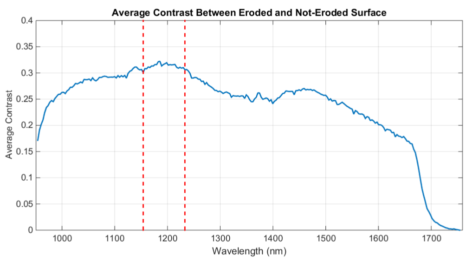


Figure 4: Average contrast between eroded and not-eroded surface

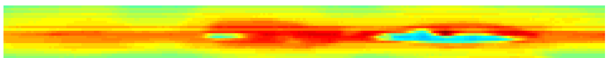
As the hyperspectral camera outputs 256 bands between 950nm and 1800nm before any further processing is performed, it was necessary to determine what the optimal bands to use were. This was done be manually selecting a region of eroded and non-eroded surface. The difference between each eroded and non-eroded surface was calculated, an average was taken and this was performed for each band. It was found that the bands between 1154nm and 1233nm were the best bands to use for the analysis, see Figure 4.

B. Classification

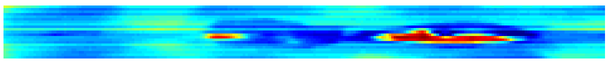
Having determined an appropriate band it was then possible to create a single image from each hyperspectral image, see Figure ??. This was created by first selecting the leading edge of the blade and then 10 pixels either side of this edge was selected, the rest of the data was discarded. The image shows the first two damage types, from right to left, however the third is not quite visible.

C. Image Flattening

To try and improve the contrast of the images, the surface of the wind turbine blade was assumed to have the geometry of a circular pipe. This profile was then subtracted to flatten the image. This increased the contrast between the eroded and non-eroded surface and the results are shown in Figure 5.



(a) RGB image created from SWIR hyperspetcral image



(b) Image after surface subtraction

Figure 5: Image after surface subtraction

V. Conclusions

Having compared the processed results, see Figure 5, to the high resolution camera, see Figure 3 it is clear that there is more detail shown from the hyperspectral images. Specifically the depth of the erosion indicated by the intensity of the image. However for field applications such as condition monitoring this added information is not necessarily useful. Currently the damage is classified into four main categories using standard imaging techniques it is possible to do this therefore for this application hyperspectral imagery may not be necessary. However there are many other applications for the technology in this field.

References

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[2] P. Brøndsted, H. Lilholt, and A. Lystrup, “Composite materials for wind power turbine blades,” Annu. Rev. Mater. Res. 35, pp. 505–538, 2005.

[3] D. Rivkin and L. Silk, Wind Turbine Operations, Maintenance, Diagnosis, and Repair, Jones & Bartlett Publishers, 2012.