QIRT'2022

10.21611/qirt.2022.1003

16th Quantitative InfraRed Thermography Conference

Detection and Localization of Premature Flow Transitions on Rotor Blades

by Ann-Marie Parrey*, Michael Sorg*, Andreas Fischer*

* *University of Bremen, Bremen Institute for Metrology, Automation and Quality Science, Bremen, Germany*

Abstract

Defects or contaminations on a wind turbine's rotor blade can lead to wedge-shaped regions with turbulent flow, which can decrease the energy output of the wind turbine. An automated algorithm is proposed, which detects turbulence wedges in thermograms even for low contrast-to-noise ratios by using prior knowledge about the wedge shape. The algorithm is verified with simulated thermograms and validated with a measured thermogram of a rotor blade of an in-service wind turbine. Even at a contrast-to-noise ratio of 2, all turbulence wedges are detected and their dimensions are quantified. Additionally, the results are mapped to the blade's geometry to realize 3D thermography.

1. Introduction and Aims

To maintain the optimum efficiency of wind turbines, defects or contaminations on the leading edge of the rotor blade, which can emerge from rain [1], hail or insects [2], need to be monitored. Disturbances on the rotor blades can cause changes in the boundary layer flow of the blade, leading to more turbulent flow in the shape of a wedge, a so-called turbulence wedge [3]. Additional turbulent flow can lead to acoustic emissions [4], an increase of drag and a decrease of lift as well as aerodynamic imbalances [5]. These factors can decrease the annual energy production, making a condition monitoring of the wind turbines' rotor blades necessary. To minimize downtime costs, a condition monitoring without stopping the wind turbine is essential. Furthermore, a measurement technique that works without modifications and contact to the blade is desirable. These demands are fulfilled by thermography, which can visualize different flow regimes in process and without contact to the blade [3]. For the detection of the turbulence wedges, the pixel intensities in thermographic images are typically evaluated [6]. However, the low image contrast between the turbulence wedges and their surrounding in thermograms of real, in-service wind turbines impedes an intensity gradient-based detection, as the intensity difference between neighbouring pixels is not large enough to be reliably detected.

A model-based image processing algorithm is introduced which uses a priori knowledge about the wedge shape of the turbulence wedges to improve the detection rate of turbulence wedges in thermographic images, especially those of low contrast. Simulations and experiments on in-service wind turbines characterize the capabilities of the chosen measurement approach. A subsequent transformation onto the blade geometry renders the results comparable in-between different thermograms without dependency on the measurement setup, as thermograms from different measurement days are often taken from separate camera angles or with a varied yaw angle of the wind turbine.

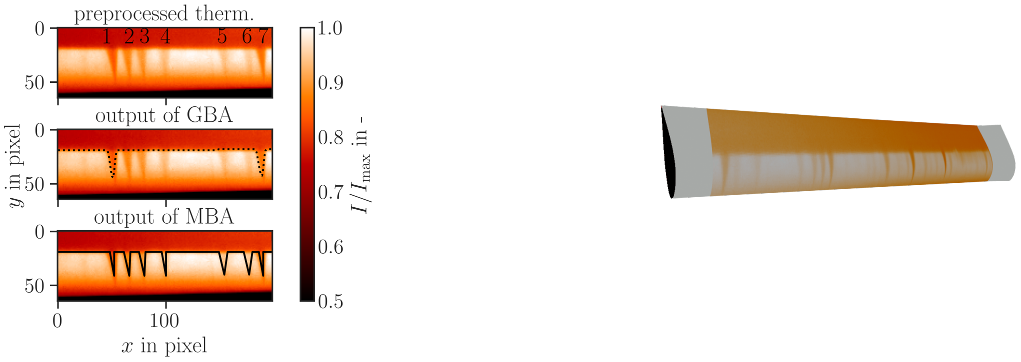
2. Measurement Approach

To detect the turbulence wedges on the rotor blade, the blade itself is first distinguished from the background of the thermogram and the natural transition line is identified using a gradient-based method. A priori, it is known that the turbulence wedges only occur in the image area between the natural transition line and the leading edge, so that the further image analysis is restricted to this image area. The positions of the turbulence wedges are detected by cross-correlating artificially generated wedge-shaped templates of various sizes with the thermogram. Minima in the cross-correlation function across the whole image width correspond to a good match between the template and the image, and therefore indicate the positions of the turbulence wedge along the natural transition line. Next, the sizes of the turbulence wedges are determined by correlating templates of various sizes with each wedge at the identified positions. The size of the template with the highest correlation value is set as the size of the turbulence wedge at the respective position. As a measure of the total area with turbulent flow, the sum over all areas of the individual turbulence wedges is calculated. To visualize the detected turbulence wedges independent of the measurement perspective, a 3d geometric mapping is implemented to transfer the image coordinates into the coordinates of the blade.

3. Results

To verify and characterize the model-based algorithm, it is applied to simulated thermograms, which are modelled according to real thermograms with a given position and size of the turbulence wedge. As a result, at least $88\,\%$ of the turbulence wedges' area can be detected even at a contrast-to-noise ratio (CNR) of 2, which remain undetected by the state-of-the-art, gradient-based algorithm.

Furthermore, the model-based algorithm is applied on a real thermogram of an in-service wind turbine from a measurement distance of $100\,\mathrm{m}$. In the thermogram, turbulence wedges with different CNR values are visible, see Figure 1(a). As a result, the state-of-the-art, gradient-based algorithm only detects two out of seven turbulence wedges with the highest CNR values, while the model-based algorithm detects all seven turbulence wedges. This results in a detected turbulent area for this specific thermogram of $63.9\,\%$ of the manually determined reference area, while the gradient-based algorithm only detects $29.1\,\%$ of the total turbulent area. Together with parameters like the measurement distance, the hub height and the blade geometry of the wind turbine, the thermogram is mapped onto the blade geometry to visualize a 3d thermogram, see Figure 1(b).



(a) **(b)**

Fig. 1. *(a): Thermogram of an in-service wind turbine with seven turbulence wedges (top), which are numbered in black. The output of the gradient-based algorithm (GBA, middle) and the output of the model-based algorithm (MBA, bottom). Notice the reduced color scale. (b): Thermogram, mapped onto the blade geometry.*

4. Conclusion and Outlook

A model-based algorithm using template matching successfully detects all turbulence wedges in a thermogram of an in-service wind turbine. Especially the detection of low-contrast turbulence wedges is successfully implemented, compared to gradient-based algorithms. After a geometric mapping onto the geometry of the rotor blade, the results can be compared between images taken from different angles. As a next step, the intensity of the turbulence wedges and the impact on the energy loss could be investigated as well as the dynamic behavior of turbulence wedges during a rotation of the wind turbine.

This research was funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) within the project PreciWind (03EE3013A).

References

[1] MH Keegan, DH Nash, and MM Stack. On erosion issues associated with the leading edge of wind turbine blades. *Journal of Physics D: Applied Physics*, 46(38):383001, 2013.

[2] GP Corten and HF Veldkamp. Insects can halve wind-turbine power. *Nature*, 412(6842):41–42, 2001.

[3] D Traphan, I Herráez, P Meinlschmidt, F Schlüter, J Peinke, and G Gülker. Remote surface damage detection on rotor blades of operating wind turbines by means of infrared thermography. *Wind energy science*, 3(2):639–650, 2018.

[4] K Latoufis, V Riziotis, S Voutsinas, and N Hatziargyriou. Effects of leading edge erosion on the power performance and acoustic noise emissions of locally manufactured small wind turbine blades. *Journal of Physics: Conference Series*, 1222:012010, 2019.

[5] J Kusnick, DE Adams, and DT Griffith. Wind turbine rotor imbalance detection using nacelle and blade measurements. *Wind Energy*, 18(2):267–276, 2015.

[6] D Gleichauf, M Sorg, and A Fischer. Contactless localization of premature laminar–turbulent flow transitions on wind turbine rotor blades in operation. *Applied Sciences*, 10(18):6552, 2020.