Passive infrared thermography as an inspection tool for operational wind turbine rotor blades

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The growing wind energy infrastructure presents a significant challenge in the maintenance and operation of wind turbines (WT) and their intricate components. An important aspect of WT maintenance is the inspection of wind turbine rotor blades (WTB) to ensure the overall health and safety of the turbine. This inspection process involves both visual and mechanical examinations of the blades to identify any indicators of damage or wear that could compromise their performance and, consequently, the structural integrity of the entire WT system. The complexity of WTBs is compounded by their ever-expanding dimensions, exceeding 100 meters in length for 16 MW WT systems, and their multi-material composition. Within this context, passive infrared thermography emerges as a potential alternative to conventional contact- or proximity-based inspection methods. Unlike active thermography, passive thermography uses solar radiation and ambient temperature variation for thermal contrast, eliminating the need for traditional heat lamps, flash, or laser-based techniques. A novel inspection method has been developed to semi-autonomously assess wind turbine blades (WTBs) while the wind turbine (WT) is operational, from ground level. This approach leverages optimal thermal contrast, which depends on prevailing weather conditions during field measurements, enabling the visualization of both external and internal features of the WTBs through post-processing techniques. In this study, thermal data obtained through passive thermography is compared with contemporaneous visual imagery to definitively classify observed features in thermal images as either surface or sub-surface features. This analysis, coupled with corresponding weather conditions, provides valuable insights into the capabilities and limitations of the inspection technique. Additionally, finite-element-based (FE) thermal simulations of a WTB section are employed to parametrically assess the influence of weather conditions, beyond those observed during field measurements, based on a validated model. In addition, the thermal images also consist of thermal signatures of leading-edge turbulence due to possible leading-edge erosion in WTBs. These are primarily vortices, and their shape and size depend on the morphology of the damage as well as the rotational speed of the WTBs. The inspections are accompanied by automatic data evaluation of the thermal signatures. To improve the precision of erosion damage identification, a fully convolutional network (FCN) is employed, trained, and tested using over 1000 annotated thermographic blade images. Additionally, the study introduces strategies for grouping smaller damage indications and simplification rules based on realistic thermal imaging resolutions. As leading-edge erosion could potentially lead to annual energy production (AEP) losses, this technique could prove to be a powerful tool in establishing the presence of damage and the resulting AEP loss.