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Blade Deflection and Tower Oscillation Sensing of Full-scale Wind Turbines with Automotive Lidars

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Abstract: Testing of full-scale wind turbine blades and tower by the traditional sensors, such as strain gages and accelerometers, is expensive, arduous, and time-consuming. In this study, we investigate a novel technique to accelerate prototype wind turbine testing under different atmospheric conditions by applying automotive lidars. A proof-of-concept field measurement was conducted, scanning the DTU V52 wind turbine with a frequency-modulated-continuous-wave (FMCW) automotive lidar at the Risø campus of the Technical University of Denmark (DTU). It was observed that the upper part of the tower was displaced by about 7 cm after the wind turbine had been stopped. The obtained power spectral density diagram shown that the dominant frequency related to the tower's oscillation is about 1.25 Hz. These results show that automotive lidars may have a great potential to be integrated into the wind energy industry to provide accurate measurements of blade deflection and tower oscillation, which will speed up the testing process and reduce the time-to-market of new turbine models.

1. Introduction

As modern wind turbine rotors reach an enormous diameter of 260 m, they are more prone to failure and damage [1]. Currently, strain gauges or optical fibers embedded in wind turbine towers and blades are primarily used for the structural health monitoring, dynamic load response, and damage identification. As reported in [2], a typical 50-meter utility-scale blade requires about 200 strain gauges, while the installation of those gauges takes at least three weeks and is very labor-intensive. To perform accurate testing, high-sensitivity sensors are needed, which can cost \$300 to \$1400 each. In light of these realities, it is imperative to move beyond the classical methods of using embedded sensors.

Contrary to the *in situ* methods mentioned above, there are alternative techniques such as photogrammetry with multiple cameras observing markers on the turbines or using a scanning laser Doppler vibrometer (SLDV). Photogrammetry has been implemented in the digital image correlation (DIC) system that measures dynamic response at many discrete points of the structure in three dimensions. However, the separation between cameras, the distance required to cover the interest field of view, and the susceptibility to outdoor conditions may limit the application of this approach for large full-scale structures [2].

High performance lidars have been widely used in a variety of applications, including atmospheric studies [3], wind energy meteorology [4], space-based research [5], and autonomous vehicles [6]. The latest advances in automotive lidar enable them to map the surroundings of a car in real-time, with camera-level resolution up to 1000 lines and 30 times per second. There are several mature products available in the market now, such as the first 4D lidar Aeries™ II (shown in Figure 1) from Aeva Inc. [7] and 3D lidar Avia or Tele-15 from Livox [8]. The automotive 4D lidars measure 3D positions by thousands of points with a precision of a few centimeters at distances up to 500 m. Additionally, the velocity (minimum precision of about 3 cm/s) is detected instantaneously for every pixel. Apart from these, the 4D lidars are also capable of detecting small objects, even low-reflectivity objects like tire fragments, and can resist interference from sunlight and light from other lidar sensors.

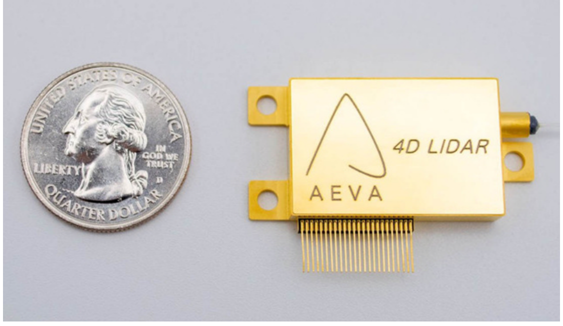

Figure 1. Picture of the 4D automotive lidar from Aeva Inc. with a very compact size due to the lidar-on-chip design © [7].

Being aware of the capability of automotive lidar measurements, we did a trial field experiment with the 4D Aeva lidar, by placing it about 70 m west of the DTU V52 wind turbine and scanning the whole structure, as depicted in Figure 2. The frame rate of the lidar was set to be 10 Hz and the measurement period lasted for 154 seconds after the wind turbine was turned off. The maximum horizontal field of view (FoV) of the lidar was 120° with 80 nominal lines per frame, while the narrow FoV was about 35 °. The lidar output includes instant velocity, reflectivity, position (x, y, z), and point confidence, which can be used to calculate the blade deflection and the tower displacement.

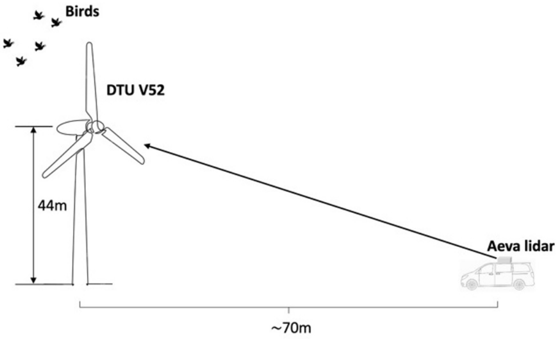

Figure 2. Experiment setup at DTU Risø campus. The Aeva lidar was mounted on a car that was parked about 70 m from the DTU V52 wind turbine with the rotor diameter of 52 m.

2. Preliminary results

Figure 3 shows the point clouds of the scanned wind turbine (with the rotor diameter D of 52 m and the hub height of 44 m), after correcting the data coordinate with the elevation angle of the lidar.

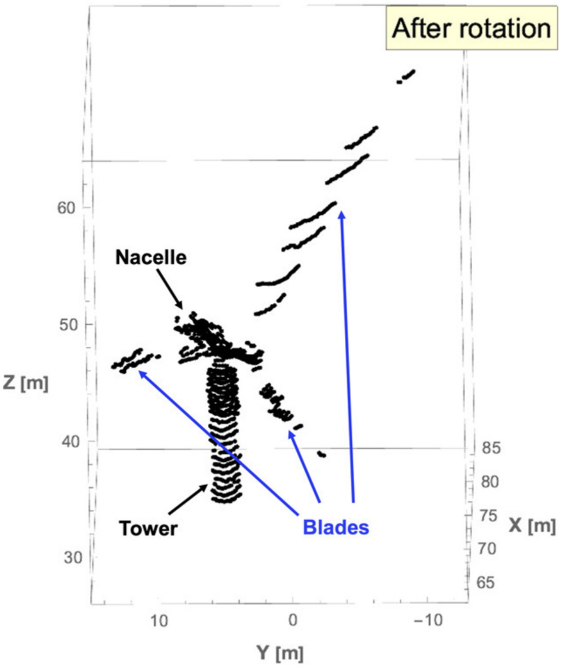

Figure 3. A snapshot of the scanned point clouds of DTU V52 wind turbine at the Risø campus.

This study primarily focused on the oscillation behavior of the tower by fitting a frustum with gradually decreasing diameter so that the mean displacement of the upper 12 m could be determined based on the lidar data measured. As can be seen in Figure 4, the maximum mean displacement along the x-axis, which is the propagation direction of the laser beam, was approximately 7 cm. In addition, Figure 4 also depicts the tower's oscillation behavior, which was dominated by a frequency of around 1.25 Hz in the power spectral density (PSD) diagram in Figure 5. The results indicate that the light automotive lidars could be a viable alternative to the traditional embedded sensors, as they can be mounted on the turbine spinner to capture the real-time deformation throughout the three blades as well as placed on the ground to measure the oscillation of the turbine tower under environmental conditions.

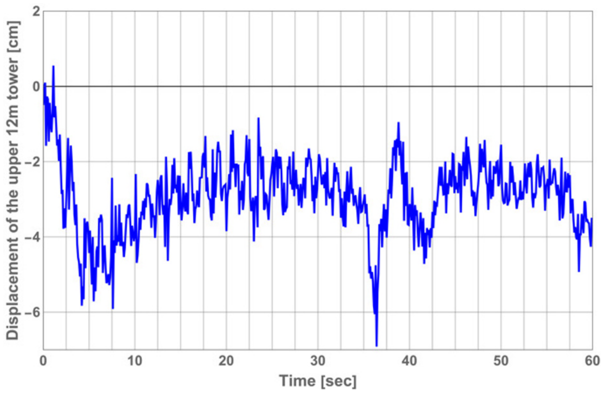

Figure 4. Mean displacement of the upper 12-meter tower in one minute after the wind turbine was stopped.

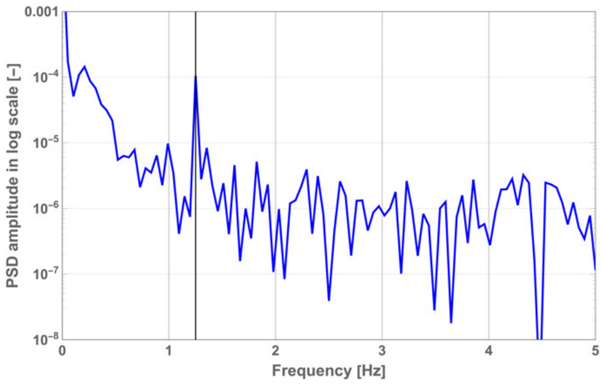

Figure 5. Power spectral density (PSD) diagram for the tower's oscillation.

3. Discussions and conclusions

This abstract presents a preliminary study to apply automotive lidars to measure displacements of DTU V52 wind turbine tower during downtime. The mean displacement of the upper 12 m tower was about 7 cm, with an oscillation frequency of 1.25 Hz. Despite the lack of benchmark studies and blade deflection analysis, the promising results indicate that automotive lidars may be a technical alternative to strain gauges to test prototype turbines, for example, measuring blade deflection and turbine tower oscillation. It is necessary, however, to conduct further investigations, for example, comparing blade deflection with high-resolution cameras at DTU Large Scale Facility and installing the lidars on the turbine spinner to observe the deflection during operation.

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