LASER VIBROMETRY FOR WIND TURBINES INSPECTION

R. Ebert, P. Lutzmann, C. Scherer, N. Scherer-Negenborn, B. Göhler, F. van Putten
Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB
Gutleuthausstraße 1, 76275 Ettlingen, Germany
reinhard.ebert@iosb.fraunhofer.de

Abstract: We report about a development of a new 1.5 µm laser vibrometer system to measure vibrations of rotating blades of wind turbines up to a distance of several hundred meters featuring a very precise image-based tracking system.

1. Introduction

The use of wind turbines, and therefore the need to monitor and analyse their performance, is growing steadily. Turbines tend to vibrate strongly, and laser Doppler vibrometry can supplement the existing on-board sensors for health monitoring these wind turbines [1, 2]. The application areas include condition monitoring, fault diagnostics and sound emission inspection, but also validation of simulation models for wind turbines. Early fault detection can protect against catastrophic conditions and sudden breakdowns.

Laser vibrometry can solve this problem by allowing non-contact measurement of the vibrations of a wind turbine from a distant sensor on the ground. For example the vibration characteristics of the whole blade surface can be determined with no need for built-in sensors or attached marks. Desired measurement distances (given the heights of modern wind turbines) will be ~ 250 m or more, and “eye safe” 1.5 µm laser Doppler vibrometers are appropriate for the laser safety requirements.

Wind turbines with large moving blades are difficult subjects for commercial laser Doppler vibrometers (LDVs). These LDVs are suited to scan static objects, or spinning objects viewed from a point on their spin axis, but not for objects like turbine blades that move through large viewing angles. Therefore the goal was to design and develop a new system allowing measurement of the vibration characteristics of rotating turbine blades.

2. General system description

The system consists mainly of two parts: an image-based tracking unit and an in-house-developed laser vibrometer. A fixed camera is mounted at the base of a pan/tilt system (PTU). It records images of the wind turbine and forwards these to software that processes the images and builds a model of the rotary motion from the data. With the help of this information, the pan and tilt head is positioned so that the laser beam of the laser vibrometer mounted on the PTU automatically follows a certain spot on the rotating turbine blades (Fig.1).

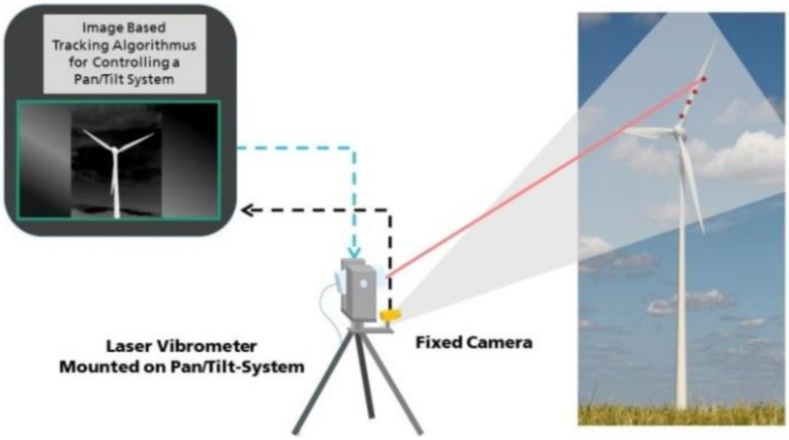

Fig. 1: Principle system configuration.

2.1 Tracking system

To manage the tracking task, three components are added to the system. Firstly a PTU capable to perform high dynamic movements under a high command rate with proper repeatability, secondly a camera working in the same spectral band like the measurement laser, providing sufficient spatial resolution, and thirdly a computer equipped with all the hardware to capture the camera images, evaluate them, and control the PTU all in real time.

The computer is powering a multi thread application, where the main thread drives a state machine, controlling all courses of events. Other threads do the bookkeeping of system time for the incoming frames with highest priority, launch speed commands to the PTU with high priority, handle the image presentation with low priority, and calculate updated model representations of the turbine with lowest priority. The usage of a multi core computer is preferred, as time critical threads are able to work in parallel.

Two main tasks are solved with the development and usage of appropriate algorithms. Firstly the turbine's wing tips have to be detected and properly located within the incoming images. Here, accuracy is crucial for the overall performance of the tracking system. Secondly a set of wing tip records, representing 2D positions at certain times, has to be used to approximate all parameters determining a 3D model of the turbine. Parameters are converged for the center of rotation, the radius, the orientation of the rotor plane relating to the camera's position, even for the focal length of the camera. Furthermore we determine the wing phases of the 3D model with every incoming frame and calculate the current rotational frequency. Based on this model we are able to predict wing positions within a limited range for random points in time. These times are given by the ability of the PTU to take a new command. A prediction range of 200 milliseconds is sufficient to compensate for all the latencies in the system.

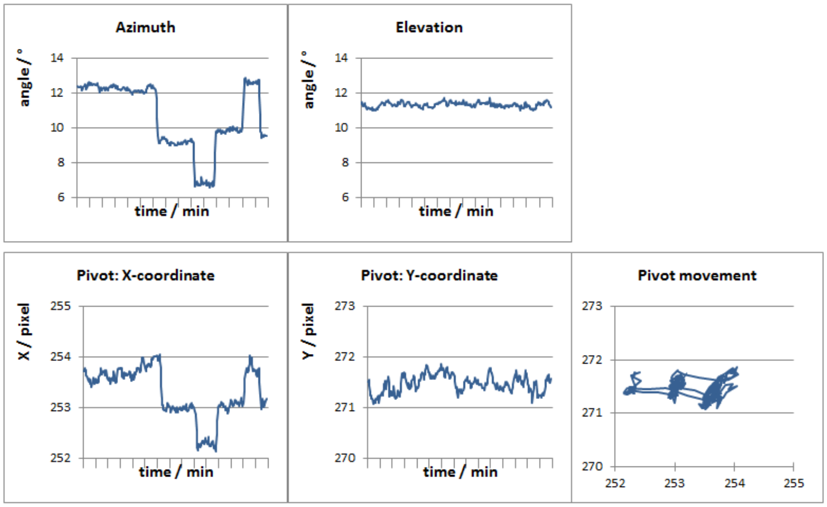

Fig. 2: Estimated values of the 3D model in comparison.

The orientation of the rotor plane relating to the camera's position can be diagrammed as azimuth and elevation angles. Fig. 2 shows 3D model results for a sequence of 15 minutes. Controlled Azimuth movement of the turbine can be clearly recognized to be in sync with pivot movement. The model is working with sub-pixel accuracy.

For the laser spot to hold the position on the rotor blade within a small range two closed control loops are needed. The first one is based on the knowledge about the current pan and tilt angles reported by the PTU itself. Using this information together with the aimed angles, updated pan and tilt speeds are calculated to be programmed next. This control loop alone is at least able to keep the laser spot on the blade at a radius where the blade width is still wide. Now a hotspot detector is used to detect the floating spot in every image. So we determine the offsets in dependence of the pan and tilt angles and alter the movements with the next turn for compensation. Turn by turn all recurring offsets get compensated. Using this optical control loop we reach the aimed accuracy of 0.4 mrad maximum direction error.

With the beginning of a new measurement the tracking system needs to be initialized. To keep the effort for the operator as small as possible, certain concepts were introduced. Firstly a start sequence leads the operator to move the spot first onto the rotor hub and then down the pole slightly outside the rotor radius. Even this task could be automated later. Secondly all sizes are kept transformed to the sensor and processed in pixel pitch units. Thirdly parallax errors arising from the distance between the PTU and the camera are disregarded. This does not compromise the overall accuracy, as all positioning errors are compensated together by the optical control loop. So the operator is relieved from knowing or measuring real sizes as the height and the radius of, or the distance to the rotor. He does not even have to know the angle to the rotor hub or the focal length of the camera. Last is an advantage if a zoom lens is used.

Following previous concepts only the absolutely necessary tasks are left to the operator. First find an appropriate measurement place to put the system there. Limits are given by a maximum measurement distance and the effective viewing angle onto the turbine. First should not exceed 400 metres and second should not differ more than 30° from on axis viewing. After the system has been started the camera has to be aligned for the rotor hub being in the centre of the image. Then a focal length has to be chosen, so that the complete rotor is pictured, but as big as possible. After the laser is activated the initialisation phase will be processed for the system being ready for measurements. Now certain positions on a chosen blade could be reached or an automated measurement pattern processed.

2.2 Laser vibrometer

The in-house-developed laser vibrometer is a fibre-based system and operates in a bistatic transmitter/receiver configuration at a wavelength of 1.5 µm (Fig. 3). With an output power of several 100 mW, a spectral line width less than 1 kHz and a field of view of 75 µrad, this system is optimised for performing medium-range measurements up to about one kilometre. A special feature is an implemented polarisation diversity technique to improve the signal-to-noise-ratio [3], degraded by the occurrence of dynamic speckle effects during the blade rotations.

To collect data from the rotating blades we have developed in-house hardware. The macro Doppler shift is compensated via an automatic frequency control (AFC), and the carrier is automatically searched for if it has been temporarily lost. When the system is located about 300 m from the wind turbine to measure large wind turbines, a varying macro Doppler shift in the range of +/- 40 MHz must be compensated. All acquired samples are stored as I&Q data via a National Instruments receiver where the effective sampling rate automatically adapts to the IF bandwidth, thus reducing the data amount.

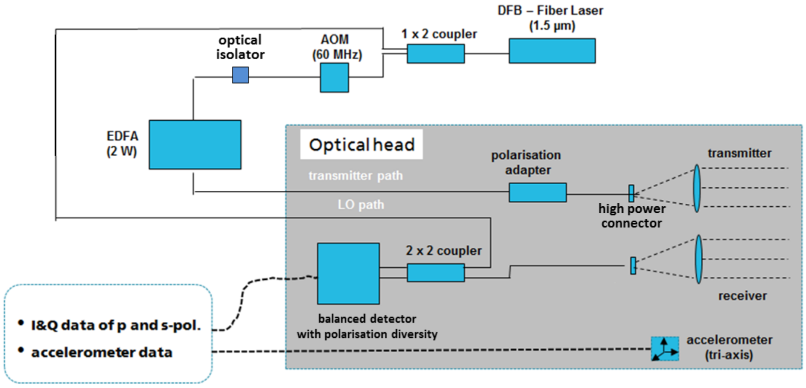

Fig. 3: Principle of the optical setup.

3. Conclusions

We have developed a new system for remote and contactless measurement of the vibration characteristics of stationary structures, especially the blades of rotating wind turbines. The system is based on an image-based tracking system and an in-house-developed 1.5 µm-laser vibrometer. Some successful tests were done with a scaled down model wind turbine. Measurements on real wind turbines are recently under way and the first results will be presented.

4. References

[1] P. Lutzmann ; B. Göhler ; F. van Putten and C. A. Hill, "Laser vibration sensing: overview and applications", Proc. SPIE 8186, Electro-Optical Remote Sensing, Photonic Technologies, and Applications V, 818602

[2] Laser Vibrometers Make Non-contact Vibration Measurements on Wind Power Plants, Polytec InFocus 2/2008, www.polytec.com/infocus

[3] A. Dräbenstedt, “Diversity Combining in Laser Doppler Vibrometry for Improved Signal Reliability”, AVIELA 2014, AIP Conf. Proc.1600, 263-273