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Energy-Autonomous Wireless Sensor Node for Monitoring of Wind Turbine Blades

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Summary:
In this contribution, we propose an energy-autonomous wireless sensor node for monitoring wind turbine blades. To allow a placement of the sensor node on the leading edge of the wind turbine blade with minimal influence to its performance, the electronics have to be ultra-thin and mechanically flexible. The concept of the sensor system is presented with a main focus on the eigenfrequency analysis of the rotor blade based on MEMS accelerometers. The sensor system is demonstrated on a small-scale wind turbine blade with a length of 1.07 m.

Keywords: wireless sensor node, energy-autonomous, eigenfrequency analysis, predictive maintenance, wind turbine monitoring, MEMS accelerometer

Motivation

Wind turbines are exposed to harsh environmental conditions, which have a particularly strong impact on their rotor blades. In order to be able to determine the present state and predict aging effects, it is of great interest to acquire local measurement data on the rotor blade itself. This can contribute to a safe operation of wind turbines after its intended life span and reduce safety downtimes. For this, the monitoring of ice layer thickness and the detection of mechanical peak loads due to impacts for example of birds, bats, ice shedding or wind gusts will be investigated. For this purpose, an energy-autonomous, ultra-thin and flexible wireless sensor system is required to be retrofittable.

In the following, we present the concept of a wireless sensor node. Furthermore, an eigenfrequency analysis is implemented and evaluated on a test setup to subsequently estimate the power consumption for energy-autonomous operation.

Concept of the Wireless Sensor Node

Eigenfrequencies are affected by alterations in geometry and material parameters and can, therefore, be exploited to detect faults in rotor blades. The eigenfrequencies can be obtained by a spectral analysis of the rotor blades vibration measured with MEMS accelerometers [1]. Modern MEMS accelerometers provide ultra-low-power operation modes with high sampling rates for spectral measurements or for continuously detecting mechanical impacts. Here, we implemented a continuous impact detection (ID) with a wake-up at a threshold of 30 g to detect randomly occurring mechanical peak loads with the accelerometer Analog Devices *ADXL273* featuring a measurement range of up to 200 g. A vibration signal is obtained by the accelerometer Bosch Sensortec *BMA400* with optimized resolution in the measurement range of 16 g either at scheduled intervals or after an impact is detected. The vibration signal is read out from the accelerometers memory into a microcontroller (µC) and is further processed according to Fig. 1. The eigenfrequencies are extracted and transmitted (Tx peaks) with an integrated 2.4 GHz radio transceiver.

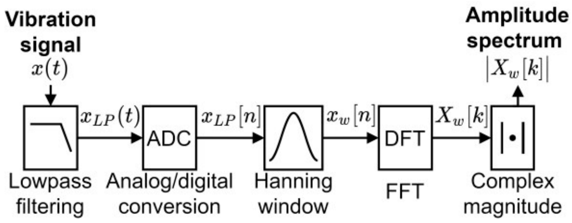

Fig. 1. Block diagram of the spectral analysis.

The first five obtained eigenfrequencies are transmitted to a base station. Thereby, long-term changes for a predictive maintenance database can be acquired. The used microcontroller Nordic *nRF52840* is mostly operated in a sleep mode with a real time clock (RTC) for scheduled tasks. A prototype of the sensor node was fabricated on a 0.6 mm thick FR4 substrate shown in Fig. 2. A subsequent sensor node will be integrated on a flexible printed circuit board with a 200 µm polyimide substrate together with a low-profile battery and energy harvester resulting in a total thickness of less than 1.3 mm.

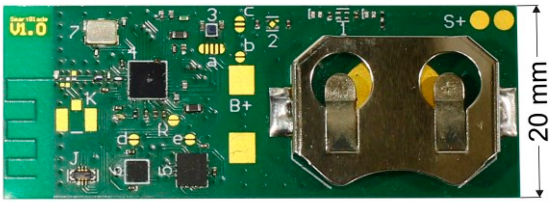

Fig. 2. Picture of the wireless sensor node.

Demonstration on a Small-Scale Rotor Blade

The eigenfrequencies of a small-scale rotor blade were determined by the wireless sensor node and evaluated with a scanning laser Doppler vibrometer. The 1.07 m long rotor blade is composed of a glass fiber reinforced polymer procured from *IstaBreeze®*.

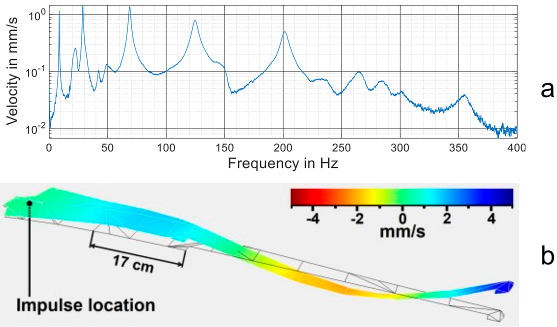

Fig. 3. Measurement results of the scanning laser Doppler vibrometer: (a) Average amplitude spectrum of the entire rotor blade. (b) Graphical representation of the third flap-wise mode at 68.83 Hz.

The statically fixed rotor blade was excited at the bottom side with a mechanical impulse generated by an electrodynamic shaker with an attached force sensor at the hammer tip. With this setup, almost solely flap-wise modes have been excited. The sensor node was positioned at the tip of the rotor blade, with the further analyzed acceleration axis, facing out of the flat side of the rotor blade.

Tab. 1: Accuracy of the eigenfrequency analysis of the first three flap-wise modes.

Flap-wise mode	Vibrometer: Frequency in Hz	Sensor Node: Frequency in Hz
1st	8.44 ± 0.08	8.6 ± 0.2
2nd	28.83 ± 0.08	29.0 ± 0.2
3rd	70.00 ± 0.16	69.9 ± 0.2

Results

Based on the coherently scanned surface of the rotor blade with the laser Doppler vibrometer, the eigenmodes can be visually determined with an exemplary of the third flap-wise mode given in Fig. 3 (b). The corresponding eigenfrequencies can be matched to the averaged spectrum of all points in the scanned area in Fig. 3 (a) and the spectrum obtained by the wireless sensor node in Fig. 4 (b).

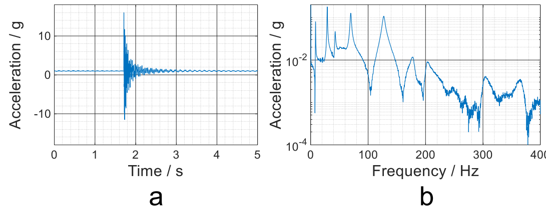

Fig. 4. Measurement result of the wireless sensor node: (a) Vibration signal in the time domain before applying a Hanning window. (b) Vibration signal in the frequency domain.

In Fig. 4 (a), measurements of an excitation impulse can be seen with an exponentially decaying amplitude in the time domain measured with 800 Hz. A fast Fourier transform (FFT) is exploited with 4096 samples to obtain the eigenfrequency analysis (EFA) in Fig. 4 (b). The eigenfrequencies of the first three flap-wise modes are averaged over 30 measurements and listed in Tab. 1.

Tab. 2: Current consumption of the sensor node at an operating voltage of 1.8 V.

Tasks	Current in µA	Duration in ms
ID & RTC	5.3 ± 0.7	-
µC & EFA	6520 ± 783	5119.00 ± 0.02
Tx peaks	7520 ± 903	0.62 ± 0.02

With the averaged current consumptions of the described tasks listed in Tab. 2, the applicability of the MEMS sensor for continuous impact detection for an energy-autonomous sensor node is shown and an estimation of measurement and transmission intervals for future work can be derived.

Acknowledgement

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References

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