Radar-based Detection of Birds at Wind Turbine Installations: Results from a Field Study

Jochen Moll
Department of Physics
Goethe University of Frankfurt
Frankfurt, Germany
moll@physik.uni-frankfurt.de

Ashkan Taremi Zadeh
Department of Physics
Goethe University of Frankfurt
Frankfurt, Germany
taremizadeh@physik.uni-frankfurt.de

Moritz Mälzer
Department of Physics
Goethe University of Frankfurt
Frankfurt, Germany
maelzer@physik.uni-frankfurt.de

Jonas Simon
Department of Physics
Goethe University of Frankfurt
Frankfurt, Germany
simon@physik.uni-frankfurt.de

Viktor Krozer
Department of Physics
Goethe University of Frankfurt
Frankfurt, Germany
krozer@physik.uni-frankfurt.de

Christian Kramer
Wölfel Engineering GmbH + Co. KG
Höchberg, Germany
kramer@woelfel.de

Herbert Friedmann
Wölfel Engineering GmbH + Co. KG
Höchberg, Germany
friedmann@woelfel.de

Andreas Nuber
Wölfel Engineering GmbH + Co. KG
Höchberg, Germany
nuber@woelfel.de

Manfred Dürr
Volta Windkraft GmbH
Ochsenfurt, Germany
duerr@voltawind.de

Dimitry Pozdniakov
HF Systems Engineering GmbH & Co. KG
Kassel, Germany
Dimitry.Pozdniakov@hubner-germany.com

Rahmi Salman
HF Systems Engineering GmbH & Co. KG
Kassel, Germany
salman@nts.uni-due.de

***Abstract*—Radar technology in the mm-wave frequency band is a promising approach for the detection of birds and bats at wind turbine installations in order to reduce fatalities either by direct collision of the animals with the rotor blades or through barotrauma. In this paper we present an FMCW radar system with 1 Tx and 9 Rx operating in the Ka-band from 33.4 GHz to 36.0 GHz. The radar system is installed at the tower of a 2 MW wind energy plant about 95 m above ground. The data acquisition is described in this paper including the real-time processing pipeline, followed by exemplary bird detections. Also the detection of drones, serving here as an artificial flying object with a defined flight path, will be presented and discussed. Validation is performed by concurrent camera recordings.**

***Index Terms*—Wind turbines, FMCW radar system, bird detection, Range-Doppler processing**

I. Introduction

The detection of birds with radar technology has a long history starting in 1945 using X-band radar systems [1]. A variety of similar radar systems have been proposed in the meantime such as Robin radar [2] or Merlin radar [3]. Most of the existing avian radar systems operate in the microwave frequency band and use a rotational scanning combined with a high gain antenna to cover a large area such as a complete wind park. Those surveillance radars are well suited for wide area monitoring and for the detection of larger birds such as eagles, red kites or storks which all have a significant radar crosssection. In this paper, we use mm-wave radar systems and operate thus at higher frequencies. Due to the smaller wavelength it is possible to measure even smaller flying animals such as singing birds and bats. Such a staring radar system has advantages in terms of detection rates and agility.

Several radar systems have been used in the context of bird detection at wind turbine installations. A first example is the bird scan radar proposed in [4] which is used to monitor bird migration through a wind farm. In addition, Wasserzier et al. [5] demonstrated bird monitoring in wind farms.

II. Field Installation: Experimental setup and monitoring approach

A. Sensor system installation

Fig. 1 illustrates the radar system installation at the tower of a wind energy plant about 95 m above ground. The radar system operates in a frequency-modulated continuous wave (FMCW) mode from 33.4 GHz to 36.0 GHz based on a sweep time of 400 µs. The output power is about 1 W. The arrangement of the transmitter (Tx) and receiver (Rx) is optimized in terms of the point spread function [6] with a centralized Tx and three Rx on each leg. Horn antennas with a gain of

The authors gratefully acknowledge the financial support of this research by the Federal Ministry for Economic Affairs and Energy (grant number: 0325791A and 0324323C).

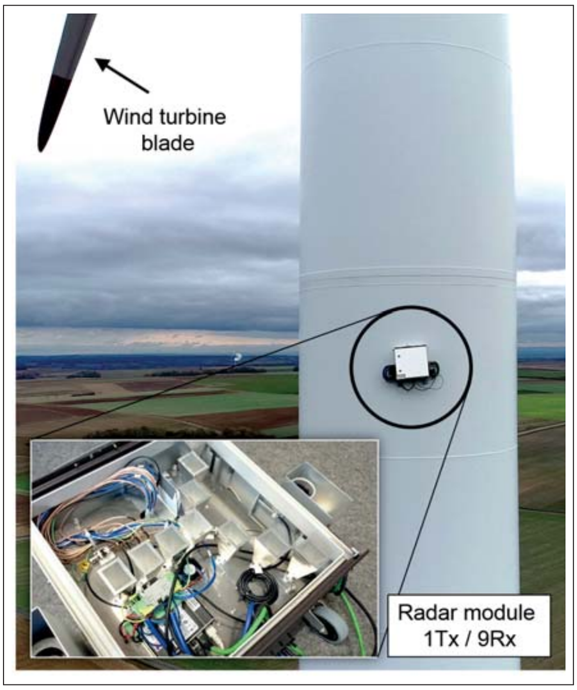

Fig. 1. Radar system installed at the tower of a 2MW wind energy plant about 95 m above ground. The FMCW radar operates in Ka-band from 33.4 GHz to 36.0 GHz and consists of one Tx and nine Rx-modules.

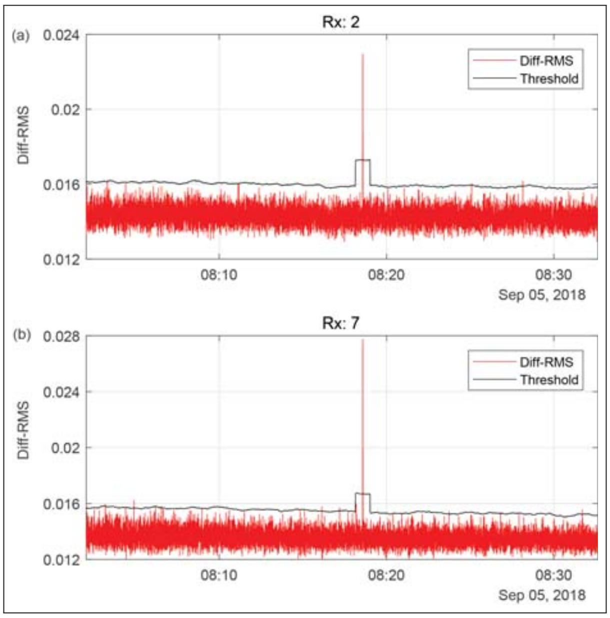

Fig. 2. Diff-RMS for two radar channels (a) Rx: 2 and (b) Rx: 7. The peaks in both curves indicates that both radar receivers were able to detect the bird event independently and automatically.

about 24 dBi are used in the transmit and receive path. More information about the systems architecture can be found in [7].

B. Signal processing strategy

Algorithms for real-time and batch processing have been implemented in this study to detect flying objects and to study their flight behaviour.

1) Real-time detection of flying objects: The radar system must decide quickly and automatically about the presence or absence of a flying animal. Therefore, activity indices have been investigated previously [8]. The real-time architecture of the proposed radar system is based on the raw data delivered by each receiver. Based on a trigger signal the useful signal portion is first segmented and then processed by the inverse Fourier transform [9]. Transforming the time axis to the distance domain using the speed of light c, leads to range profiles that provide distance information about the flying objects. A waterfall diagram of such range profiles is called radargram.

The real-time detection of bats and birds is based on a differential approach where one range profile is subtracted from the next. From this differential signal the root-mean-square (RMS) is computed. A flying object leads to strong signal changes and to a peak in the differential RMS (called Diff-RMS in the remaining paper). A detection threshold is based on the statistical properties of the differential signal and follows the approach presented in Ref. [7].

2) Range-Doppler processing: The Range-Doppler algorithm (RDA) is widely used to determine the velocity of moving objects by measuring and processing the Doppler shift in the received signals [10]–[13]. For calculating the velocity and distance of birds and bats an accurate measurement of the reflected frequency is required. The shift between the transmitted frequency and received frequency is an indication of the bird's speed. An object moving towards the radar would lead to a shortening of the wavelength (negative sign of radial velocity). If the object moves away from the radar this process reverses (positive sign of radial velocity). The algorithm exploits the mean frequency of the transmitted FMCW signal as the carrier frequency for calculating the Doppler shift. According to [14] the relationship between Doppler frequency f_D and emitted frequency f_{Tx} is given by

$$f_D = f_{Rx} - f_{Tx} = \frac{2 \cdot v_r \cdot f_{Tx}}{c_0}, \tag{1}$$

where f_{Rx} is the received frequency and v_r is the radial velocity. It has to be mentioned, that the calculated velocity has a certain error since the mean frequency of the FMCW radar was used as a reasonable approximation.

To form the Range-Doppler (RD) map the RDA computes an FFT for range compression. Next, the data must be transformed to the Range-Doppler domain by an azimuth FFT [15]. The range-Doppler map provides information about the position and velocity of the object for a particular time interval. Plotting the RD map over time, leads to the objects flight path.

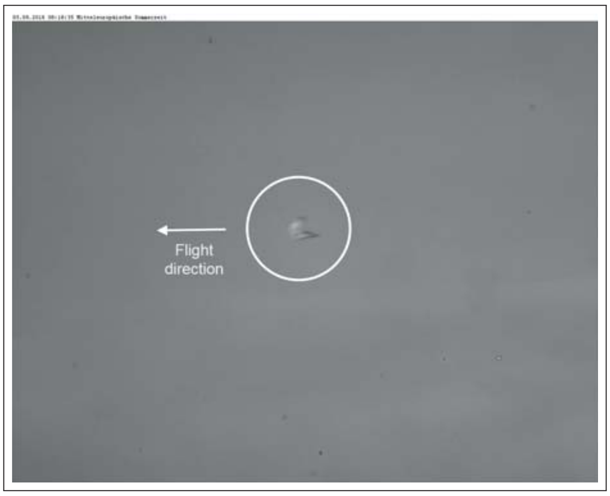

Fig. 3. Result of the concurrent camera-based detection of the birds flight path.

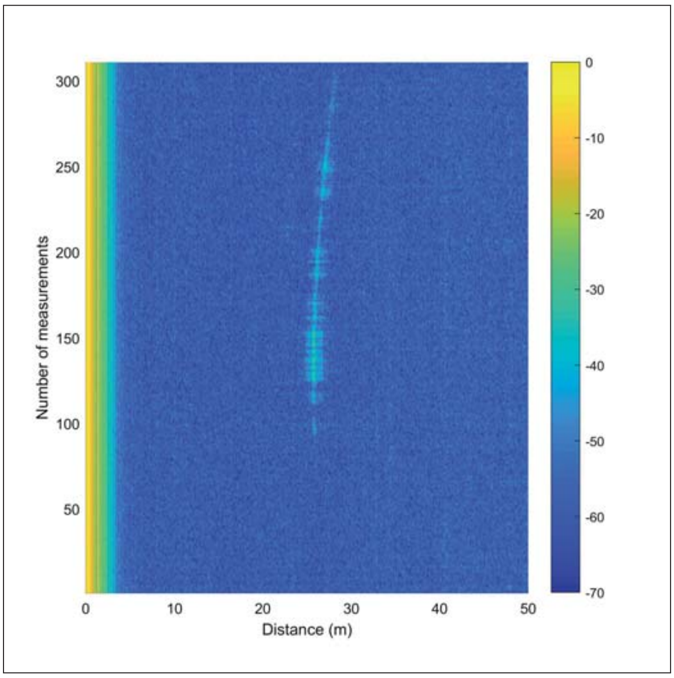

Fig. 4. Radargram for the detection of the bird shown in Fig. 3.

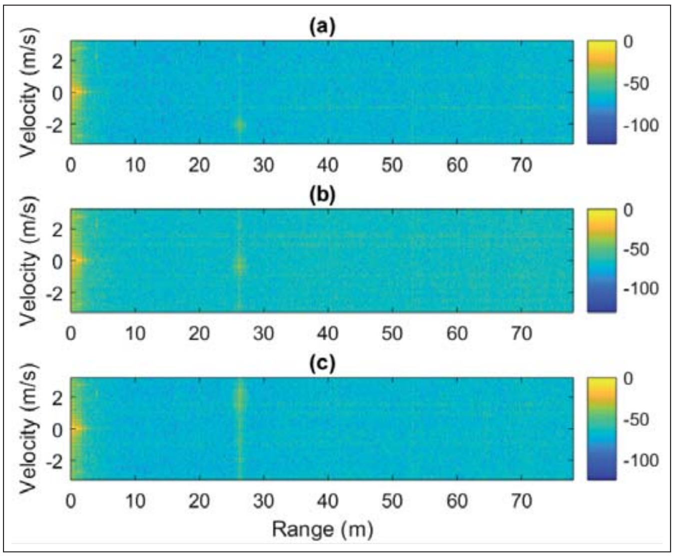

Fig. 5. Range-Doppler map of a bird: (a) target is moving towards the radar. (b) target is located in front of the radar and has no radial velocity, and (c) target is moving away.

III. Results

A. Bird detection example

Fig. 2 illustrates the Diff-RMS curves for two different radar channels, i.e. Rx: 2 and Rx: 7. In both cases a sudden peak can be observed at the same point in time that intersects the statistically defined threshold. Since this event was recorded during the day it was possible to record a video of the bird shown in Fig. 3. Other bird detections were recorded during the night where no camera-based validation was possible.

Fig. 4 depicts the corresponding radargram showing that the bird passed the radar at a distance of about 25 m. In addition, Figure 5 illustrates three different time intervals of the Range-Doppler map. In subfigure 5(a) the bird is flying towards the radar with a speed of approximately $|v_r| = 2\frac{m}{s}$. The flight direction is given by the negative sign of the velocity. In subfigure 5(b) the bird has a radial velocity $v_r = 0$ which means that the animal is located exactly in front of the radar. Finally, subfigure 5(c) shows the bird is flying away with $|v_r| = 2\frac{m}{s}$.

B. Drone Detection

The drone is considered in this work as an artificial bird model that provides a defined flight path relative to the radar. However, compared to a bird the radar crosssection of the drone is much larger. In this work, drone detection is performed in the same way as before based on a threshold crossing. The corresponding radargram as well as a photo of the detected drone is shown in Fig. 6 and Fig. 7, respectively.

IV. Conclusions and Outlook

This paper demonstrated the installation of a multistatic mm-wave FMCW radar system at the tower of a wind energy plant, followed by the successful detection of flying birds and drones. The radar measurements were validated by real-time camera systems installed on both sides of the radar system. In the future, a reliable detection of bats and birds can lead to an adaptive wind turbine control strategy so that currently implemented shut-down algorithms leading to revenue losses for the wind turbine operators can be overcome.

Acknowledgement

The authors gratefully acknowledge the financial support of this research by the Federal Ministry for Economic Affairs and Energy (grant number: 0325791A and 0324323C).

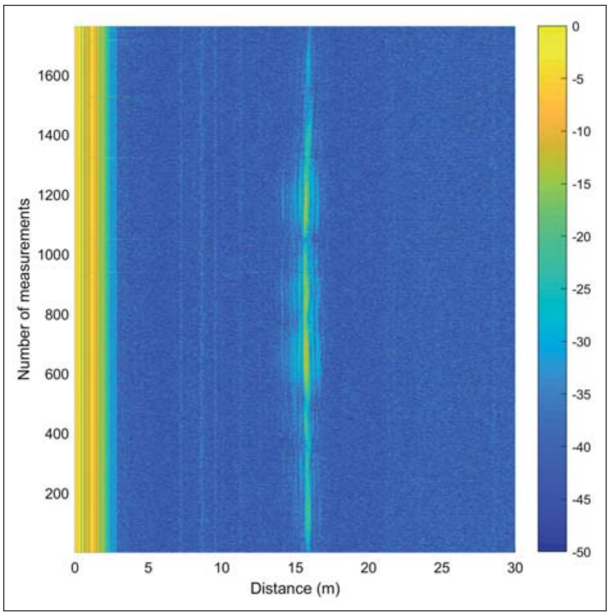

Fig. 6. Radargram for the detection of a drone where the drone moves approximately 16 m in front of the radar.

Fig. 7. Camera-based validation during drone measurement.

REFERENCES

[1] D. Lack and G. Varley, “Detection of birds by radar,” *Nature*, vol. 156, no. 3963, p. 446, 1945.

[2] S. Dirksen, “Review of methods and techniques for field validation of collision rates and avoidance amongst birds and bats at offshore wind turbines,” Sjoerd Dirksen Ecology, Tech. Rep., 2017.

[3] R. May, Y. Steinheim, P. Kvaløy, R. Vang, and F. Hanssen, “Performance test and verification of an off-the-shelf automated avian radar tracking system,” *Ecology and Evolution*, vol. 7, no. 15, pp. 5930–5938, Aug. 2017. [Online]. Available: http://doi.wiley.com/10.1002/ece3.3162

[4] R. Hill, K. Hill, R. Aumüller, A. Schulz, T. Dittmann, C. Kulemeyer, and T. Coppack, “Of birds, blades and barriers: Detecting and analysing mass migration events at alpha ventus,” in *Ecological Research at the Offshore Windfarm alpha ventus*, Federal Maritime and Hydrographic A and Federal Ministry for the Environmen, Eds. Wiesbaden: Springer Fachmedien Wiesbaden, 2014, pp. 111–131.

[5] C. Wasserzier, T. Badawy, J. Klimek, M. Caris, H. Kuschel, T. Bertuch, C. Locker, F. Kloppel, J. Wilcke, and A. Saalmann, “Radar demonstrator for bird monitoring in wind farms,” in *2018 22nd International Microwave and Radar Conference (MIKON)*. Poznan, Poland: IEEE, May 2018, pp. 119–122. [Online]. Available: https://ieeexplore.ieee.org/document/8404998/

[6] P. Arnold, J. Moll, and V. Krozer, “Design of a sparse antenna array for radar-based structural health monitoring of wind turbine blades,” *IET Radar, Sonar & Navigation*, vol. 11, no. 8, pp. 1259–1265, Aug. 2017. [Online]. Available: http://digital-library.theiet.org/content/journals/10.1049/iet-rsn.2016.0355

[7] J. Moll, J. Simon, M. Mälzer, V. Krozer, D. Pozdniakov, R. Salman, M. Dürr, M. Feulner, A. Nuber, and H. Friedmann, “Radar Imaging System for In-Service Wind Turbine Blades Inspections: Initial Results from a Field Installation at a 2mw Wind Turbine,” *Progress in Electromagnetic Research (PIER)*, no. 162, pp. 51–60, 2018.

[8] J. Moll, M. Mälzer, V. Krozer, D. Pozdniakov, R. Salman, J. Beetz, and M. Kössl, “Activity Monitoring of Bats in a Laboratory Flight Tunnel Using a 24 GHz FMCW Radar System,” in *11th European Conference on Antennas and Propagation (Paris, France)*, 2017, pp. 2541–2545.

[9] J. Moll, P. Arnold, M. Mälzer, V. Krozer, D. Pozdniakov, R. Salman, S. Rediske, M. Scholz, H. Friedmann, and A. Nuber, “Radar-based structural health monitoring of wind turbine blades: The case of damage detection,” *Structural Health Monitoring*, vol. 17, no. 4, pp. 815–822, Jul. 2018. [Online]. Available: http://journals.sagepub.com/doi/10.1177/1475921717721447

[10] I. Cumming and J. Bennett, “Digital processing of Seasat SAR data,” in *ICASSP ’79. IEEE International Conference on Acoustics, Speech, and Signal Processing*, vol. 4. Washington, DC, USA: Institute of Electrical and Electronics Engineers, 1979, pp. 710–718. [Online]. Available: http://ieeexplore.ieee.org/document/1170630/

[11] J. C. Curlander and R. N. McDonough, *Synthetic aperture radar: systems and signal processing*, ser. Wiley series in remote sensing. New York: Wiley, 1991.

[12] F. Ali and M. Vossiek, “Detection of weak moving targets based on 2-D range-Doppler FMCW radar Fourier processing,” in *Microwave Conference, 2010 German*. IEEE, 2010, pp. 214–217.

[13] A. Macaveiu, C. Nafornita, A. Isar, A. Campeanu, and I. Nafornita, “A method for building the range-Doppler map for multiple automotive radar targets,” in *2014 11th International Symposium on Electronics and Telecommunications (ISETC)*, Nov. 2014, pp. 1–6.

[14] J. Rosen and L. Q. Gothard, *Encyclopedia of Physical Science*. Infobase Publishing, 2009.

[15] I. G. Cumming and F. H. Wong, *Digital Processing of Synthetic Aperture Radar Data: Algorithms and Implementation*. Artech House, 2005.