B-FINDER SYSTEM

24 MONTH TEST REPORT FOR T-SERIES

POZNAŃ, NOVEMBER 2019

B-FINDER

CONTENTS

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1. Introduction

This Report presents the results of tests of B-finder System prototype. The tests were performed between 11.11.2017 and 11.11.2019.

The research was funded by EMPEKO S.A. and R&D grants. In 2017 EMPEKO S.A. started the project POIR.01.02.00-00-0233/16 co-financed by the National Centre for Research and Development. During this project fallowing works were done:

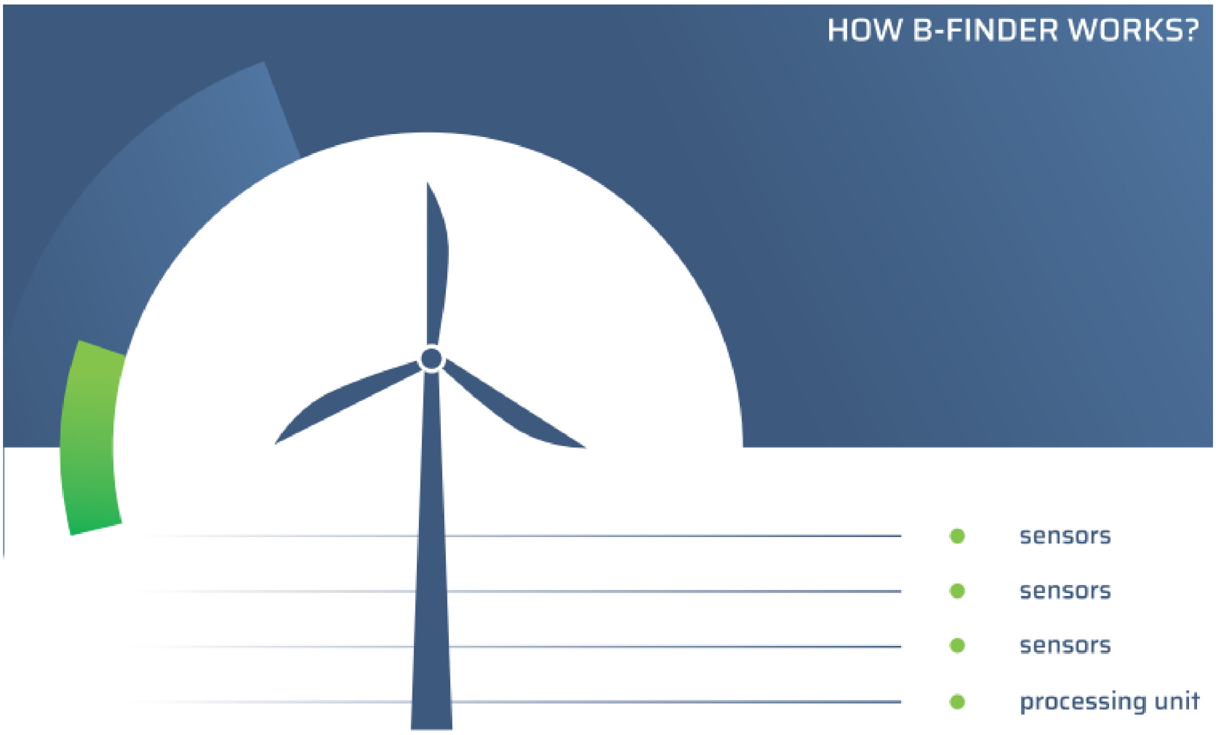
- the conceptual, laboratory, field and computing works;
- the prototype integration;
- the test field preparation;
- the prototype assembly on wind turbine;
- the prototype test in real condition started on 2017.11.11;
- the 2-year prototype test in real condition performed.

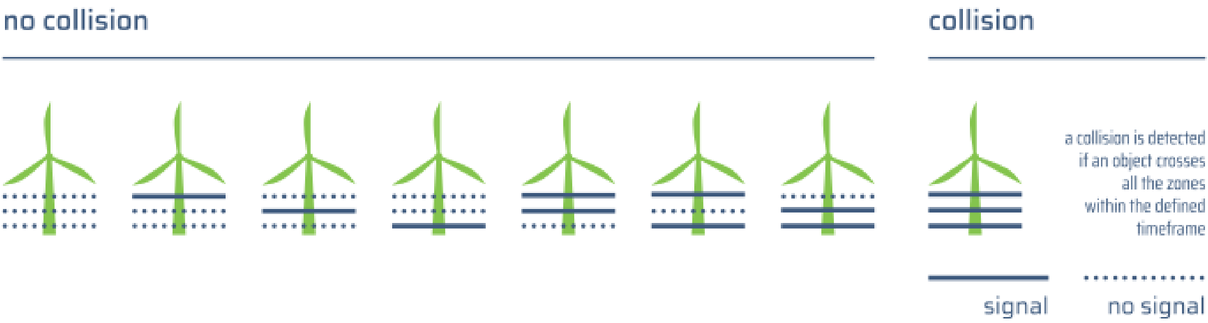
Since April 2019 the research has been a part of the project RPWP.01.02.00-30-0008/17 co-financed by Marshal Office of the Wielkopolska Region in Poznan.

This Report is the first public presentation of the results of B-finder prototype tests. The description of the hardware and software is limited and will be published in other documents. This Report is focused on general presentation of the conducted experiments and their results, which show the efficiency of detection of bat and bird fatality.

Since January 2017 the patent protection based on Polish patent P.416126 is part of the project POIR.02.03.04-30-0013/16 co-financed by Polish Agency for Enterprise Development. The patent is pending in countries on 6 continents. Today B-finder technology is patented in Australia, China, Poland, South Africa and Taiwan. Next procedures are still in progress when the report is created.

2. How B-finder works?





The basic principle of B-finder is the sequence of recordings of animal falling across the sensor zones. The fall of dead or injured animals has different parameters than the flight of those alive. B-finder system differentiates between them and reports only the fatalities. The monitoring results are available online for the user including information about the time of collision and the location of the carcass.

3. Hardware

B-finder System consists of a computing unit located inside the wind turbine tower, an antenna for remote access and external sensors attached to the tower. The internal unit is encapsulated in a rack cabin including UPS, computers and switches. The antenna, used for communication between the prototype and B-finder data center, was installed outside of the tower. However, internal installation of the antenna is also possible if the signal is strong enough. In case of an off-shore application, the satellite communication is the preferred option. The system can also be connected to the wind turbine communication network. The local area network connection and power supply for the external sensors were assembled using F/UTP cables. The sensors should be mounted at minimum two different heights on the wind turbine tower, which results in two or more sensor levels. Every level of sensors should be scanning entire 360° of horizontal view around the tower. Thus, the number of the sensors required depends on the horizontal field of view of the particular sensors used. Our prototype was equipped with three levels of sensors at 15, 30 and 45 meters above the ground. At every level, two types of sensors were installed:

1. 12 thermal cameras: FOV 32°x26°; array format 640x480
2. 4 thermal cameras: lens FOV 93°x61°; array format 320x240

Additionally, for the sake of weather condition observation and security, four video cameras with FOV 100° were installed at the lowest level. However, these cameras were not used for the detection of collision events.

Figure 1. B-finder prototype sensors on the wind turbine.

4. Software

B-finder System detects the collisions of bats and birds with the wind turbine by continuously processing the recordings from the sensors. The system runs 24/7 and is equipped with algorithms that distinguish between alive and dead animals. In case a collision occurs, the recordings of the falling body are saved as a proof of the event, along with date, time and estimated location of the carcass. The collision events are being synchronized between the wind turbine and B-finder data center in real time.

The users of B-finder system have access to the user panel, which provides information about the events. The estimated positions of carcasses are marked on a map for every event. The user can check the details about the events and view the corresponding recordings.

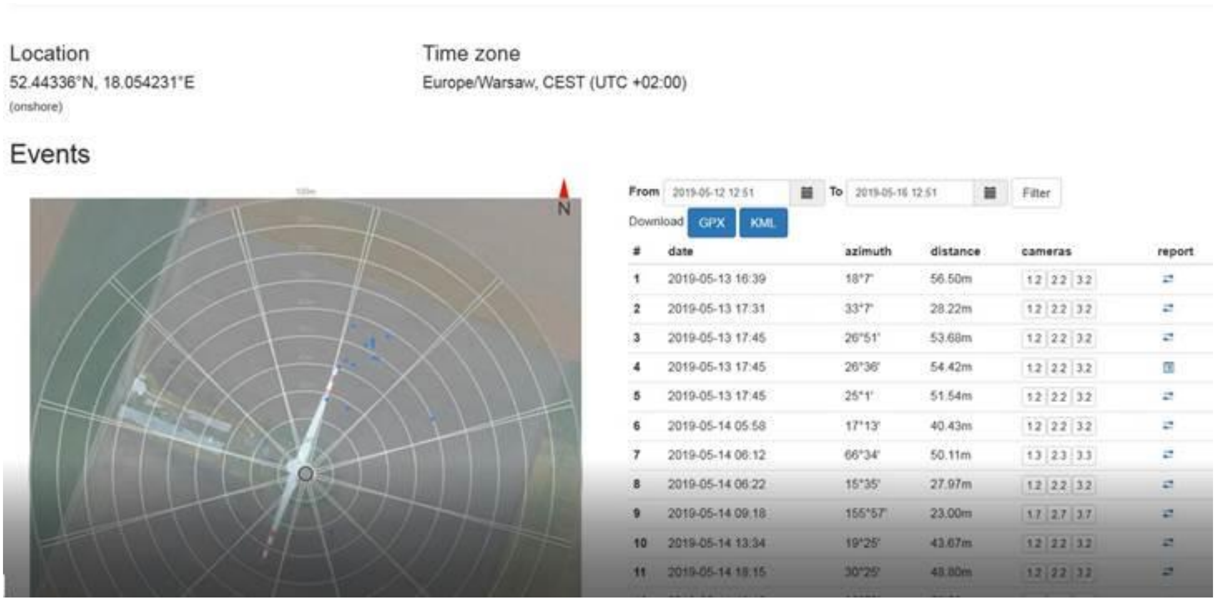


Figure 2. B-finder user panel displays the list of collision events and map of carcass locations.

For each event, B-finder system provides the following information:

- date and time of the collision (year, month, day, hour, minute);
- azimuth from the wind turbine tower to the carcass on the ground;
- approximate distance from the wind turbine tower to the carcass on the ground;
- screenshots from the sensors at the time of the event, included colored trajectories of the falling body at every level of sensors;
- movie recordings of the collision victim's fall at every level of sensors;
- KML and GPX files with the location of the carcass on the ground.

- PDF file with the Field Inspection Report, including detailed data from the field control (e.g. species recognition, carcass description, carcass pictures). This report is available once the crew completes the field control. The field control can and should be performed immediately, because the collision alert is available directly after the collision. For onshore project only.

Report. Project „Prototype", WTG 1, Event 2019-07-12 23:35

Project			
name	"Prototype"		
type	onshore		
WTG No.	1		
WTG longitude	18.054231°E		
WTG latitude	52.44336°N		
customer no	1		
agreement	B/1/9/2017		
contact customer	+48000000000		
country	Poland		
region 1	Great Poland Voivodship		
region 2	n/a		
county	n/a		
plot	n/a		
plot owner	Name Surname		
Event			
event time	2019-07-12 23:35		
event position	sector	azimuth	distance
	12	332°37'	47,83m
analysis time	2019-07-13 08:00		
analysis result	to confirm		
analyst	Name Surname		
Field control			
control time	2019-07-13 09:30		
control result	event confirmed		
event type	true		
animal	bat		
species	known		
Species name 1	*Pipistrellus pipistrellus*		
Species name 2	Common pipistrelle		
condition	death		
scavenger	no		
ground type	zea		
vegetation	100%, spacing ca. 0,7m		
vegetation	ca 250cm		
performer	Name Surname		
carcass dealing	utilized		
waste	n/a		

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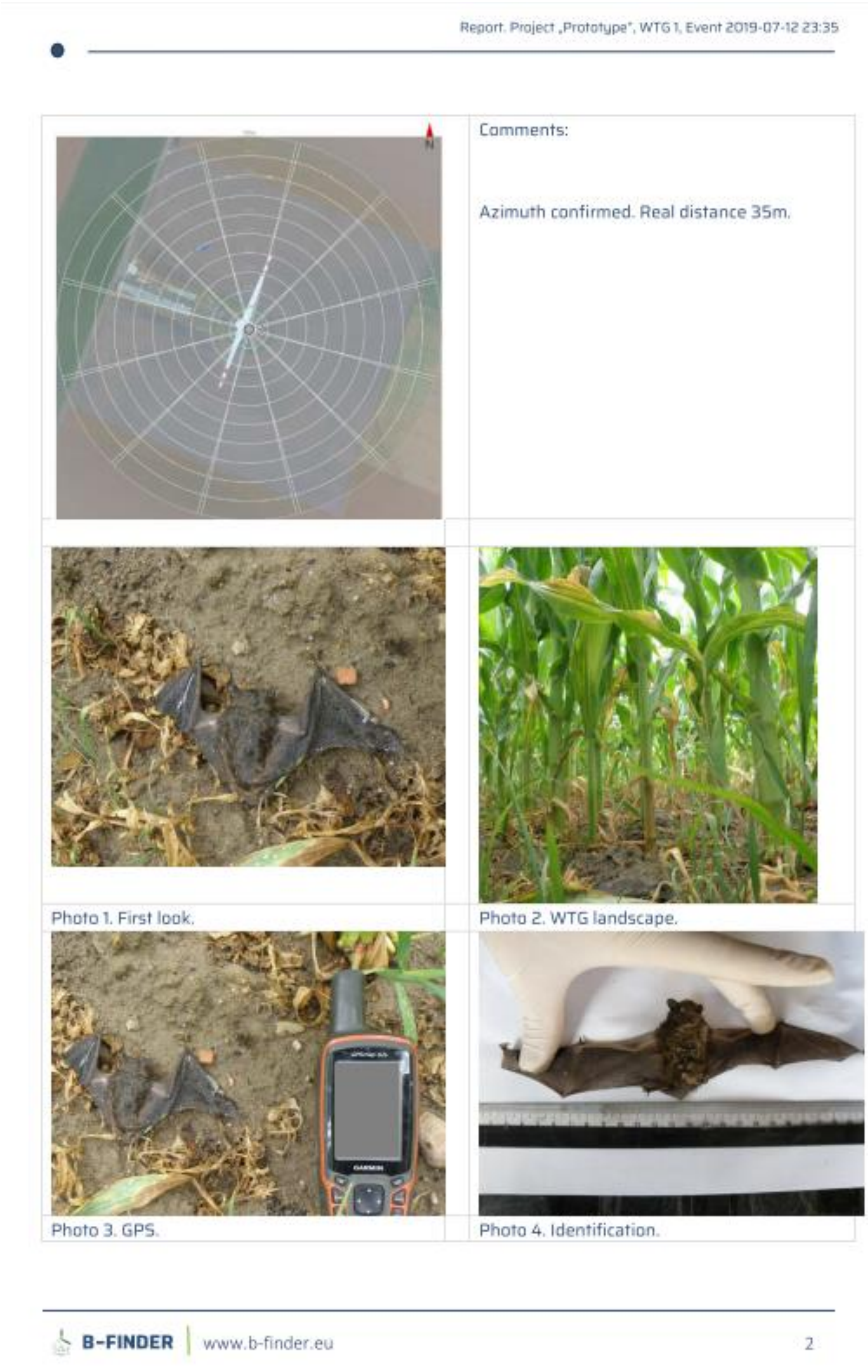
Figure 3. Example of the Field Inspection Report, page 1.


Report. Project „Prototype", WTG 1, Event 2019-07-12 23:35

Comments:

Azimuth confirmed. Real distance 35m.

Photo 1. First look.

Photo 2. WTG landscape.

Photo 3. GPS.

Photo 4. Identification.

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Figure 4. Example of the Field Inspection Report, page 2.

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5. Tests

5.1 Introduction

During the 2-year test period the system was in operation day and night. Throughout two winters, two springs, two summers and two autumns it was exposed to variable weather conditions.

The prototype was installed on the tower of wind turbine Enercon E-53 located in western Poland (temperate climate zone). The metal tower is 72 meters high, while the rotor diameter is 52.9 meters. The long tests in real conditions provided the information about the hardware endurance and gave the opportunity to perform series of tests, leading to further improvements of the software.

Figure 5. B-finder prototype in winter.

Because of the limited number of real collision cases (see chapter 5.2) and fixed length of the wind turbine's blade, the main research was based on simulated collisions at different distances from the wind tower (see chapter 5.3). This way, the results of the tests are universal and applicable to all turbine types with different blade dimensions.

5.2 Real fatality observation

Introduction

Continuous activity of the prototype installed on the wind turbine made possible to observe real fatality cases. Regular field inspections had been held by the team during the first year of tests, in order to validate the accuracy of the automatic solution. After the first year of tests the efficiency of the system was high enough to reduce the frequency of field inspections to the cases of automatically detected fatalities. Besides the field inspections, the recordings collected by the system had been analyzed every 12 hours by the B-finder team, to verify the correctness of collision recognition and distinguish real collisions from another events and noise. The results of analytical work were the most important source of information for the software's development and configuration during the two years of operation.

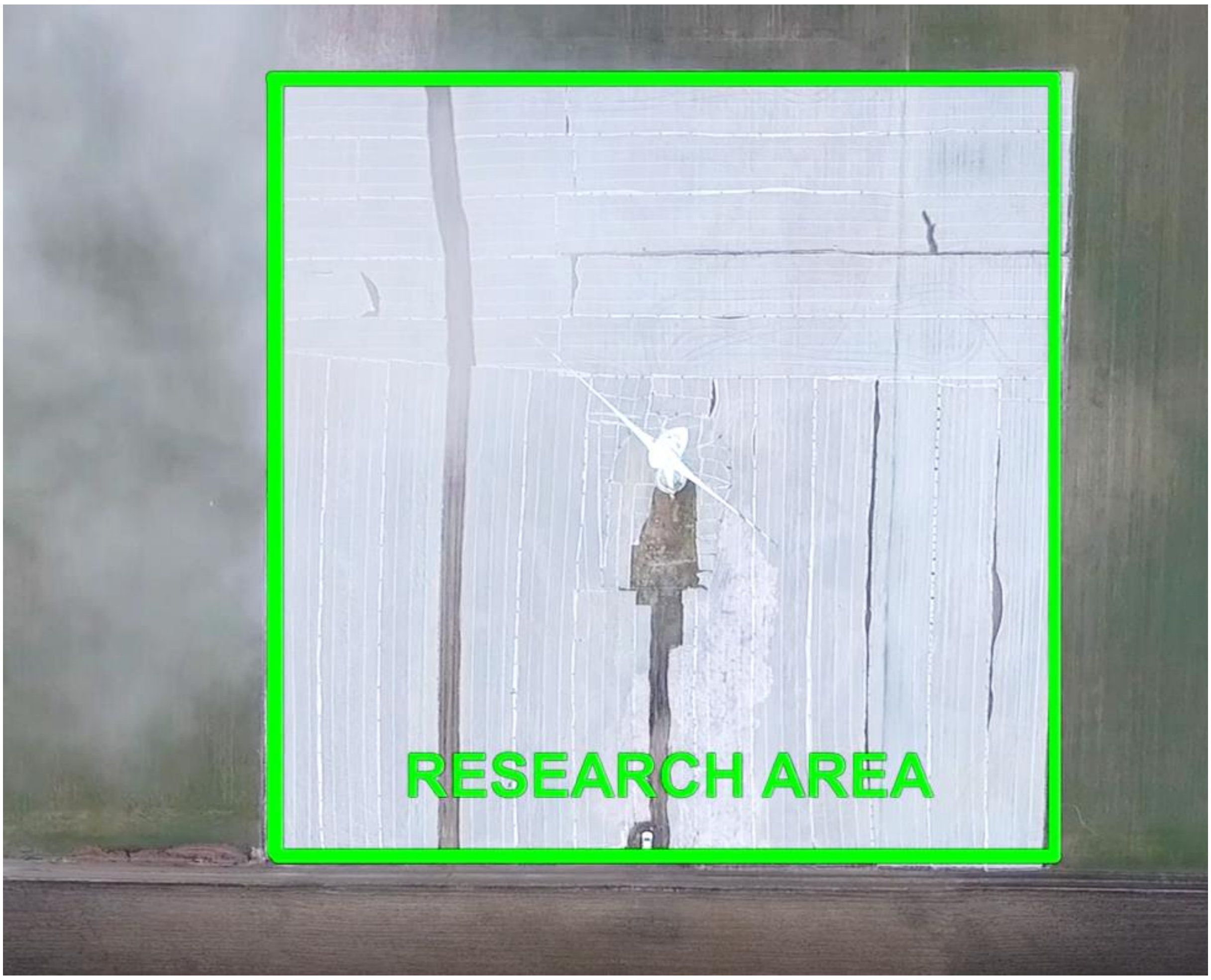


Figure 6. The test field covered with agrotextile between 11.11.2017 and 25.06.2018.

Steps done:

- test area preparation (October 2017);
- field inspections (11 November 2017 – 11 November 2018);
- recordings analysis (11 November 2017 – 11 November 2019).

In October 2017, the research area was prepared. Square area of 150x150 m with the turbine in the center was harrowed and covered with white agrotextile. The edges of the research area are 75 meters away from the turbine tower, which equals the height of the tower and three times the blade length. Such research area made the inspections more effective. After 7 months, in June 2018, the agrotextile was destroyed by weather factors and vegetation development. Then the agrotextile was removed, the vegetation cut down, moved, ground plowed and rolled. This way the test field was still flat and easy to monitor. The field had remained in such condition until the crops had been cultivated in the test field at the beginning of 2019. Wheat appeared within 25 meters from the south edge of the area, while the rest of the field was occupied by corn.

Figure 7. The test field between 25.06.2018 and 11.11.2018.

The real collision factor is random phenomena and the average number of collisions make difficult to tests the system based on the results of real fatality only. For the assessment of the efficiency in detection of collisions numerous series of simulation-tests was performed and described in chapter 5.3 below.

Test field inspections

Inspections of the test field had been performed everyday between 11.11.2017 and 03.05.2018 (6 months), every other day between 04.05.2018 and 15.09.2018 (4 months) and once a week between 16.09.2018 and 11.11.2018 (2 months). During every inspection the following information was collected:

- date and time of inspection;
- inspector name;
- weather conditions;
- live animals activity (i.e. species, sex, number, behavior, scavenger activity);
- GPS supervision information.

Figure 8. The GPS track of every field inspection is logged and documented.

The inspection crew was equipped with GPS loggers for path documentation. The inspectors had been walking along a regular pattern, looking for all objects up to 5 meters away from the path. The carcasses found were documented in the report, including GPS location and photographs.

Since 11.11.2018 field inspections had been performed only in case of collisions reported by the B-finder system.

Results

During the tests six real collision victims were found, four in 2018 and two in 2019. Two bats and two birds were found in 2018 and two bats were found in 2019 (see Table 1).

Table 1. The carcass founded on the field test.

No.	DD.MM.YYYY	Species	Distance from the tower [m]	Comments
1	11.03.2018	*Sturnus vulgaris*	1,5-28	broken into fragments
2	05.05.2018	*Alauda arvensis*	20	
3	04.07.2018	*Vespertilio murinus*	34	
4	06.08.2018	*Nyctalus noctula*	27	
5	13.07.2019	*Pipistrellus pipistrellus*	35	
6	03.08.2019	*Pipistrellus pipistrellus*	32	

Out of six victims found on the test field, five were detected by the B-finder system (Table 1; No. 2-6). The one victim not detected (Table 1, No. 1) was falling down in few parts after the crash with a blade. The reason why the system missed that case was that wide-angle cameras were inactive at that time. Wide-angle cameras are crucial for the detection of animals falling within short range from the tower, where gaps occur between the fields of view of the main cameras. The victim on 11.03.2018 was found at distance of 1.5m from the tower and few small parts of its body were found at distance up to 28m from the tower. After this event the wide-angle cameras had been introduced to the system to monitor the short range space.

5.3 Simulations of fatalities

Introduction

Because the expected number of real fatalities was too low from a statistical point of view (see Chapter 5.2), additional imitative fatalities were simulated. During the two years of research 1274 simulations of dead bats and birds falling down had been performed: 846 on the prototype, 240 on a 37-meter-high tower, 138 in the headquarter neighborhood and additional 50 tree penetration tests.

Objects used for the simulation of fatalities

Freshly dead zebra finches *Taeniopygia guttata*, Barbary doves *Streptopelia risoria*, domestic pigeon *Columba livia* and swan goose *Anser cygnoides*, as well as plastic test tubes and bottles have been used as the objects for the simulation. Real animals used for the tests were direct equivalents of real collisions. To reduce the number of freshly dead animals, plastic equivalents were calibrated and used in the majority of simulations. The advantages of plastic objects are:

- saving real animals,
- shape suitable for being carried by a rocket or a drone,
- allow for calibration of different temperature values,
- temperature emission is similar to live animals,
- durable enough for multiple use,
- various dimensions for simulating different animals.

As the first step of the calibration process the temperature of a live bird was measured using a thermal camera and a pyrometer. Several measurements were performed in different weather conditions, including various air temperatures, wind and humidity. This way the possible ranges of temperature of a live bird were defined. Additionally, the dimensions and weight of the animal were measured to choose a suitable test tube or bottle. In the next step the temperature of test tubes and bottles was calibrated to match the real case temperature. The cooling rate of the plastic objects was determined. This information is necessary to set up the initial temperature of an object properly, so that the temperature matches that of a freshly dead animal when the object is released from a rocket or a drone (the time of start of object dropping is the equivalent of the time of collision with the blade). The source of heat was warm water inside the plastic objects.

Furthermore, the amount of the water was calibrated to match the real weight of an animal being simulated.

The results of the calibration process describe the temperature and volume of water required to fill a test tube or a bottle in specific weather conditions, so that its temperature and weight during a fall test matches the temperature and weight of a live animal. This provides the necessary information to accurately simulate a live animal with a plastic equivalent thrown from a rocket or a drone. The correctness of the object's temperature was validated for each test case by pyrometer measurement done right after the object hit the ground.

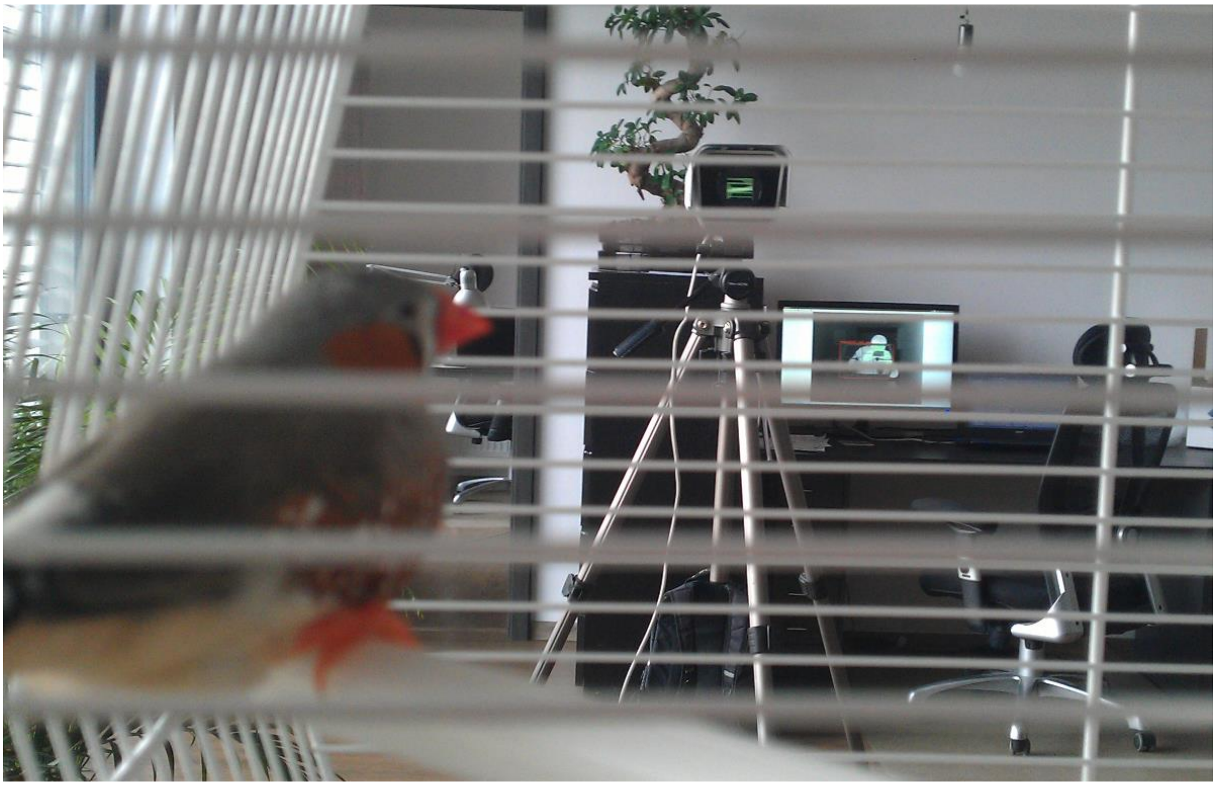


Figure 9. Zebra finch *Taeniopygia guttata* was used to measure the temperature of small birds as the input for the calibration of test tubes.

Tests outside the prototype

9 series of tests (2018.05.21; 2018.05.22; 2018.05.28; 2018.07.13; 2018.07.17; 2019.01.29; 2019.02.03; 2019.10.22; 2019.10.23) were performed in the B-finder headquarter neighborhood (see Table 2). The tests included basic examination of a single sensor, as well as simulations of falling collision victims during snow and fog (local short-term weather phenomena, possible to be explored only for a limited period of time).

Table 2. Objects used for the simulations in headquarter neighborhood (N=138)

No	Object	Size	N of simulations
1	Small test tube	4x3 cm	70
2	Zebra finch *Taeniopygia guttata*	7 cm*	33

*- measured without the tail (because it is poorly visible on the thermal camera)

7 series of basic simulations (2017.12.22; 2018.01.26; 2018.02.22; 2018.03.05; 2018.10.23; 2019.02.15; 2019.06.04) were performed on the 37-meter-high tower. In contrast to the prototype, only a single sensor had been used (see Table 3).

Table 3. Objects used for the simulations on the 37-meter-high tower (N=240)

No	Object	Size	N of simulations
1	Small test tube	4x3 cm	99
2	Large test tube	9x3 cm	18
3	Double large test tube	9x6 cm	4
4	Bottle	15 x 5 cm	16
5	Zebra finch *Taeniopygia guttata*	7 cm*	41
6	Domestic pigeon *Columba livia*	20 cm*	32
7	Swan goose *Anser cygnoides*	70 cm*	13
8	Other objects	n/a	17

*- measured without the tail (because it is poorly visible on the thermal camera)

Figure 10. The 37-meter-high tower. A screenshot of the simulation from the sensor at distance of 50m

Figure 11. The 37-meter-high tower used for experiments.

Tree penetration tests

B-finder system can also be used on wind projects located in the forests. The trees surrounding a wind turbine may, however, stop a collision victim from hitting the ground. Therefore, it is necessary to investigate what percentage of carcasses on average stop within the tree canopy. For this purpose, tree penetration tests were performed on 5 tree species: oak, pine, spruce, poplar and alder. Tests consisted in dropping objects above trees from a drone. The results for different species are:

- alder, pine – 20% of objects hung on trees,
- oak, spruce – 10% of objects hung on trees,
- poplar – 0% of objects hung on trees.

Table 4. Objects used for the tree penetration tests (N=50).

No	Object	Length	N of simulations
1	Zebra finch *Taeniopygia guttata*	7 cm	50

Results of the tree penetration tests show that not all carcasses fall on the ground after colliding with a turbine. Up to 20% of carcasses may stop within the tree canopy.

Tests on the prototype

The main 20 series of tests (2017.12.05; 2017.12.18; 2018.01.08; 2018.02.08; 2018.02.15; 2018.03.15; 2018.05.02; 2018.05.11; 2018.07.25; 2018.07.31; 2018.08.03; 2018.08.08; 2018.08.17; 2018.11.07; 2018.11.27; 2019.02.15; 2019.06.03; 2019.06.26; 2019.07.25; 2019.09.24) were performed on the prototype located on a wind turbine with the test field around. The purpose of the tests was to determine:

- input parameters of the fall of a dead animal;
- range of detection in various weather conditions;
- precision of carcass location estimation.

Drones (see Figure 12) and rockets (see Figure 13) had been used as the platforms for lifting the objects up (see Figure 14). The altitude at which the objects had been dropped was between 50 and 250 meters above the ground (see Figure 15). After every single simulation, the distance between the object on the ground after the fall and the wind tower was measured manually. The measurements were compared to the automatic location estimation provided by the B-finder system (see Figure 16) to obtain the precision of the estimation. Furthermore, the range of automatic detection was determined as the result of the tests. It describes the maximum distance at which a collision victim is detected by the B-finder system with ca. 95% efficiency. The values are presented in Table 6 for different weather conditions.

Table 5. Objects used for the simulations on the prototype (N=846).

No	Object	Length x diameter	N of simulations
1	Small test tube	4x3 cm	448
2	Large test tube	9x3 cm	72
3	Double large test tube	9x6 cm	79
4	Bottle	15 x 5 cm	90
5	Zebra finch *Taeniopygia guttata*	7 cm*	82
6	Barbary doves *Streptopelia risoria*	15 cm*	20
7	Rocket	30X2,7 cm	55

*- measured without the tail (because it is poorly visible on the thermal camera)

Figure 12. Loading a test tube onto the drone. The technician holds in his right hand a pyrometer, which is used to measure the temperature of the object just before the loading and immediately after the fall.

Figure 13. Start of a rocket used as the platform for lifting test tubes.

Figure 14. A test tube falling down after being dropped by the drone.

Figure 15. A test tube falling down after being dropped by the drone. Its flight is recorded not only by the prototype but also by the camera attached to the drone.

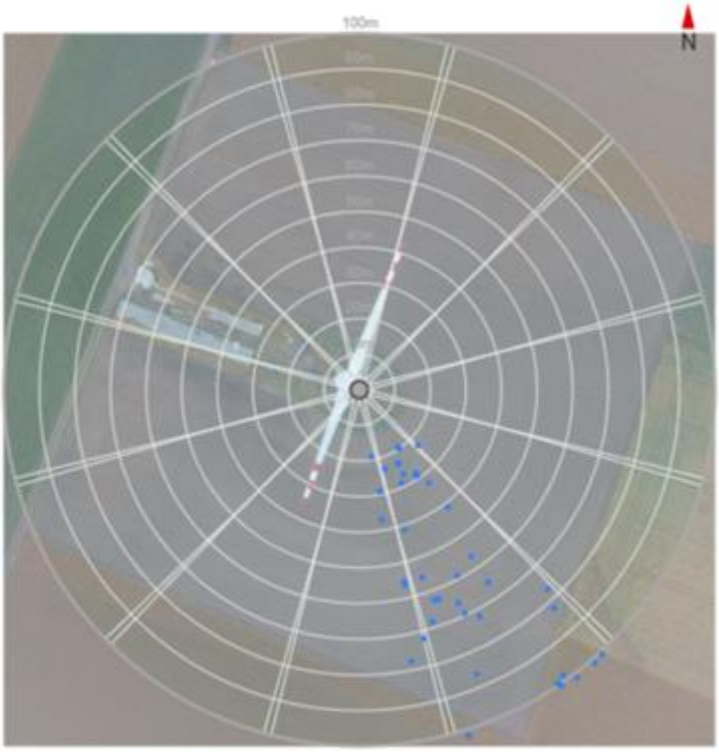


Figure 16. Locations of the dropped objects estimated by the B-finder system, shown in the user panel (tests on 2018.08.17). The automatic results were compared to manual measurements.

6. Results

6.1 Detection range

The range of detection depends mainly on the sensors used, parameters of the falling object and environmental factors.

The major parameters of the sensors are:

- optic parameters;
- array parameters;
- framerate;
- video codec.

In this research the sensor parameters were fixed (see Chapter 3). However, B-finder system can be potentially built using different sensors.

The parameters of a falling object affecting the detection are:

- size;
- temperature;
- material.

The results presented in this chapter are given for the objects described in Tables 2-6.

The environmental factors that have the biggest influence on the detection are:

- air temperature;
- rain, snow and hail;
- fog.

The factors had been varying continuously according to the weather and sunlight exposure. To take into account different environmental factors, test series were performed during different weather conditions, at different hours and seasons.

The results presented in this chapter are proper only for sensors described in Chapter 3, objects described in Tables 2-5 and environmental conditions described in Table 6.

Table 6. Detection range [m] for different objects in various weather conditions (up to given ranges all objects were detected).

Lp	date	T air [°C]	cloud [%]	other	object size [cm]				
					4x3	7x3	9x3	9x6	15x5
1	2018.02.08	- 5	0		56				
2	2018.02.15	- 3	100		50				
3	2018.03.05	- 3	50			50			
4	2018.02.22	- 1 - 0	33-50		50				
5	2018.11.27	0	100		50	50		95	
6	2019.01.29	0	100	snow	70	60			
7	2019.02.03	0	100	snow		43			
8	2018.03.15	1-3	100				100		
9	2018.01.26	5	70-100			45			
10	2019.10.23	6-7	0	fog		42			
11	2018.10.23	7	100	rain	40	45		89	100
12	2019.02.15	9	0		71				
13	2019.10.22	12-13	0	fog		31			
14	2018.05.02	14-16	100		45		100		
15	2018.07.13	15-18	100	rain	37				
16	2019.09.24	16-17	0-50			30		64	
17	2018.07.17	16-17	100	rain	36	32			
18	2018.11.07	15-17	0		45	45			
19	2018.05.11	19	100		50				
20	2018.08.08	25-28	20	night	41		50		
21	2018.07.25	26-29	33-50		40	49			
22	2019.06.03	27-29	0						77
23	2018.08.17	27-30	25		32			68	
24	2018.07.31	28-33	0-33			37			88
25	2018.08.03	30-32	10-33				47		97

Increase of air temperature decreases the detection range by up to 10% for 15x5 cm objects and up to 40% for 4x3 cm objects. On the other hand, decrease of air temperature increases the detection range. The 4x3 cm size objects are the equivalent of the smallest European and North American bats (pipistrelles *Pipistrellus sp.*) and birds (crests *Regulus sp.*), the 9x6 cm objects are the equivalent of most common bird species in rural landscape skylark *Alauda arvensis* or the biggest European bats (greater noctule bats *Nyctalus lasiopterus*).The 15x5 cm size objects (bottles and Barbary doves) are the equivalent of the smallest European and North American diurnal raptors - respectively: lesser kestrel *Falco naumanni* and american kestrel *Falco sparverius.* Species bigger than

15x5 cm (the great majority of diurnal raptors in Europe and North America) are always detected within range of at least 100 m, regardless of weather conditions. The provided dimensions of objects are corresponding to the length of birds' body without the tail, because the tail is poorly visible on a thermal camera.

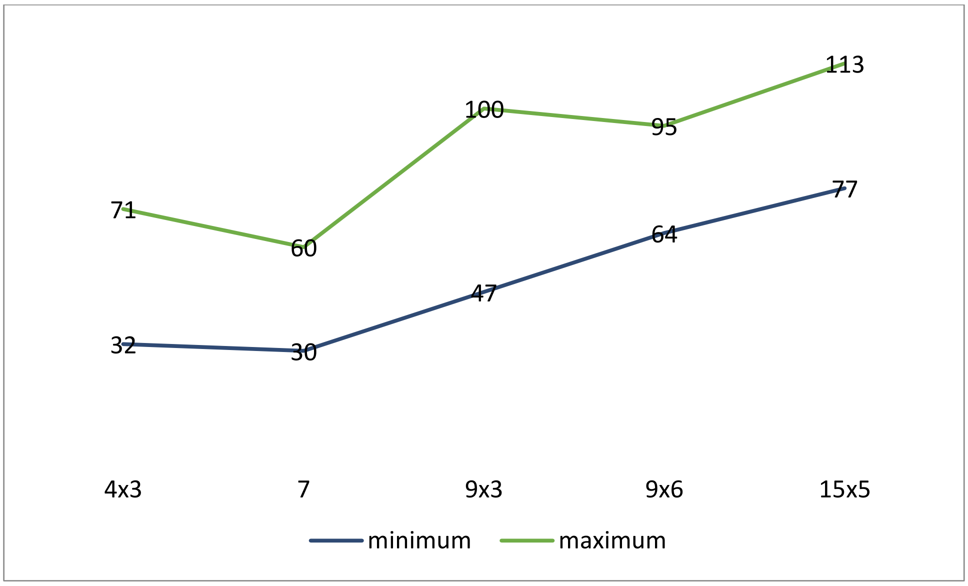


Figure 17. The minimum (in the worse conditions) and maximum (in the best conditions) detection range [m] for objects of different size [cm].

The properties of sensors used in this research, were preliminary chosen to detect all bat and bird species within the range of 50 m and raptors within the range of 100m from the wind turbine tower. The 50- and 100-meter ranges are common distances used in post-construction monitoring. The prototype created with such assumptions in mind, enables to directly introduce the B-finder system into majority of monitoring projects. The development of wind turbine rotors often results in construction of longer blades, especially in offshore projects, therefore increasing the required detection range. By the installation of proper sensors and simple configuration of the software, the B-finder system can easily be upgraded to increase the detection range. In such case, either sensors with higher matrix resolution or a bigger number of narrow-field-of-view sensors should be used. In summary, the detection range values described in this document can be tailored to the needs of a specific wind turbine. B-finder prototype configuration has optimal distance range to costs ratio.

6.2 Precision of estimating the carcass location

Besides the detection of fatality, the B-finder system calculates the approximate location of the carcass on the ground. The precision of the estimation is 10-20 m on average. The precision of azimuth is very high and equals about 5 degrees. This automatic estimation of the carcass location enables the searcher to focus only on few percent's of the entire monitoring area and brings huge savings in comparison to traditional manual searching routine. The B-finder system is superior to the old methods, which require the field crew to "blindly" walk around the wind turbine tower during every visit to the field (see Table 7). What's more, the controls in old method are based on preliminary schedule.

Table 7. Comparison of estimated search area and path length (which translate directly into labor required) for 50- and 100-meter range monitoring area using the traditional method and B-finder system.

factor	50 m radius		100 m radius	
	traditional	B-finder	traditional	B-finder
Searching area [m^2]	7850	154	31400	254
Searching area comparison [%]	100	4	100	0,8
Searching path length [m]*	1728	81	6595	81
Searching path length comparison [%]	100	4,7	100	1,2

* assuming 5 m spacing between paths

In the traditional searching method the spacing of search paths are fixed. During the prototype tests we had observed that 1 m spacing is necessary to find the carcass in vegetation higher than 20 cm. Given the carcass location, estimated by the B-finder system, the field inspection within a small region around that location was effective if the area was controlled step by step with the spacing of 1 m. Thus, the spacing of 5 m or more, commonly used in the traditional searching method, is the reason for very low or zero efficiency of traditional searching in vegetation. Otherwise, assuming 1 m spacing, in order to explore the area around a single turbine, the field staff would need to walk 8 km for a 50 m range and 31,4 km for 100 m range. In B-finder monitoring, the staff needs to walk only 0,15 km for 50 m and 0,25 km for 100 m range. These numbers show how B-finder improves the post-construction monitoring, drastically decreasing the necessary labor.

7. Conclusions

The B-finder system in the basic configuration enables:

- detection of all bats species up to 50 m from the wind tower (min. 95% efficiency);
- detection of smallest bird species up to 50 m from the wind tower (min. 95% efficiency);
- detection of all bigger bird species up to 100 m from the wind tower (min 95% efficiency);
- detection of all raptor species up to 100 m from the wind tower (min 95% efficiency);
- localization of the carcass on the ground with precision about 10 m.

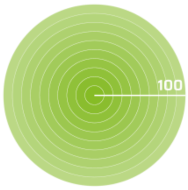
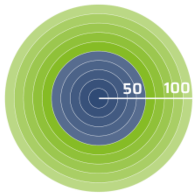
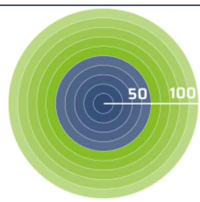
The system advantages:

- automation;
- transparency;
- measurement standard;
- immediately information about collision;
- no scavenger activity influence;
- onshore and offshore ready;
- evidence;
- time savings;
- workforce savings.

8. B-finder models

In November 2019 B-finder is available in 6 configurations characterized in Table 8.

Table 8. B-finder models available in November 2019.

						
model	TB50	TB100	TBSN50	TBSN100	TBS50	TBS100
bats detection	N/A	N/A	up to 50 m	up to 50 m	up to 50 m	up to 50 m
small birds detection	N/A	N/A	N/A	N/A	up to 50 m	up to 50 m
big birds detection	up to 50 m	up to 100 m	up to 50 m	up to 100 m	up to 50 m	up to 100 m
location precision	ca 10 m					
efficiency	ca 95%					