Bird collision monitoring system for multi-megawatt wind turbines WT-Bird®

Summary of prototype development and testing

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Cover photo by Jos Beurskens, ECN

This report presents a comprehensive summary of the prototype development and testing. The report ECN-E-06-027 provides an extensive overview.

Abstract

The effects of wind turbines on birds have been studied for almost twenty years, mainly by visual observation and radar. This has provided a good insight in the collision risks for several land-based wind farms. Still more accurate data are needed to assess the actual mortality rates and eventually the collision risks, especially for large (offshore) wind farms.

A new method for detection and registration of bird collisions has been developed that is suitable for continuous remote operation in both onshore and offshore wind farms. A prototype has been tested successfully on a land-based multi-megawatt turbine.

Compared to other methods employed so far this registration system will reduce the uncertainty in the results of the number of birds killed by collisions with wind turbines. It runs continuously and makes identification of species possible. It has been investigated whether this system can also be used for monitoring of other events in order to save costs for inspection and repair after incidents. For offshore wind farms, the WT-Bird system is in fact the only alternative to count the number of bird collisions.

Functional tests with bird dummies of only 50 grams and 6.5 cm in diameter, representing the smallest abundant bird species along the Dutch coastal region, hitting the rotating blades showed that the majority of impacts were detected. The flight track of these dummies and the collision events were clearly visible on the video registrations. Also the operational experience from endurance tests is presented.

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1. Background

For large-scale implementation of wind energy more data are needed to assess the environmental impacts, especially regarding bird collisions in large (offshore) wind farms.

During the last five years ECN has developed a system with which it is possible to detect bird collisions against wind turbines, called WT-Bird®[1]. The principle of the WT-Bird system is that a bird collision is detected by the sound of the impact (triggering) and that the species can be recognised from video images. In 2003 several prototypes have been developed and tested on turbines of several hundred kilowatts.

Based on functional specifications that have been drafted in close collaboration with project developers and ornithologists, ECN has recently built and tested a prototype on a Nordex N80/2.5 MW turbine on the "ECN Windturbine testpark Wieringermeer" (EWTW).

2. WT-Bird system development

2.1 General specifications

Below, the general specifications are listed of the WT-Bird system that is ready for application in large-scale (offshore) wind farms.

The WT-Bird system should:

Functional

1. continuously detect collisions and count the number of detected collision events;
2. store date, time and turbine number for each collision event;
3. store video registrations - and optionally audio registrations and the measured impact signals - of sufficient quality over specified time period which includes the collision event and enable remote access by the operator;
4. send an alert message to operator in case of a collision event or a failure, e.g. after an outage period;
5. operate independently from turbine and operator, including start-up and frequent self-test;
6. continue operating in case of minor failure, e.g. failure of a sensor or communication link;

Physical

7. be suitable to apply on multi-megawatt scale turbines;
8. be suitable to operate in offshore environmental conditions;
9. have simple installation with only minor modifications to the turbine;
10. have a maintenance interval of 1 year at least;

Test

11. be functionally tested after each installation according to a standard test protocol;
12. be calibrated for each configuration and type of turbine, so that the expected number of collisions can be derived from the measurements;
13. quantify the probability that birds with a weight in between 6 grams and 11 kg and a wing length in between 6 cm and 60 cm can be detected and recognised under various circumstances.

[1] The name **WT-Bird** has been registered under reference number 004333456, class 09 in the European Register, is dated 11 March 2005 and stands in the name of Stichting Energieonderzoek Centrum Nederland.

2.2 System overview

A schematic overview of the system is given in Figure 1. The prototype system consists of acceleration sensors in the blades (two in each blade). As an option one could also add sensors in the tower. The sensors in the blades are connected to a data-acquisition platform in the rotor with real-time signal processing capabilities. This platform sends a trigger signal to a PC in the tower base in case a collision is detected. The signal triggers the PC to store all sensor data and the video registrations from a user-defined period including the collision event, e.g. 20 sec. before the collision to 10 sec. after). As an option, outdoor microphones could easily be added to provide additional information on bird species, however no suitable types have been found yet, i.e. types that meet the physical requirements listed in 2.1.

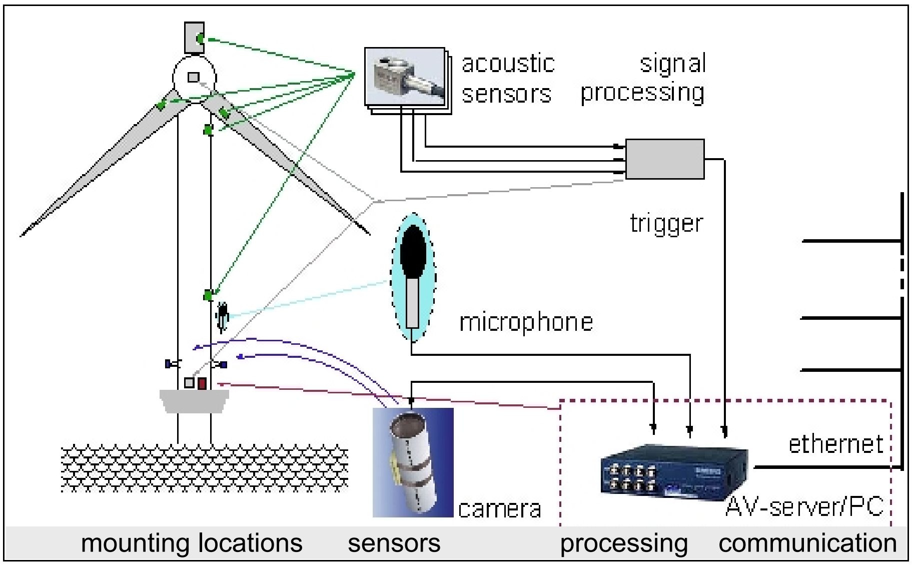

Figure 1: *Schematic overview of WT-Bird system for a single large turbine*

2.3 Prototype development

An extensive test program has been carried out to develop the prototype for multi-megawatt turbines, for instance to determine the optimal sensor locations, to develop the triggering algorithm, and to determine the optimal camera settings and camera positions. After installation of the prototype system in 2005 the test program continued to assess and improve the system reliability and performance. This included an endurance test to assess the reliability of the equipment and to improve the signal processing. Also a number of video images have been gathered to assess the image quality for various circumstances. Finally a functional test was performed, in which a number of dummies have been shot against the rotating blades.

2.4 Triggering

The aim of the triggering system is to obtain a low impact detection limit, thereby minimizing the number of false triggers caused by disturbances, such as "operational" noise from the turbine, which is illustrated in Figure 2.

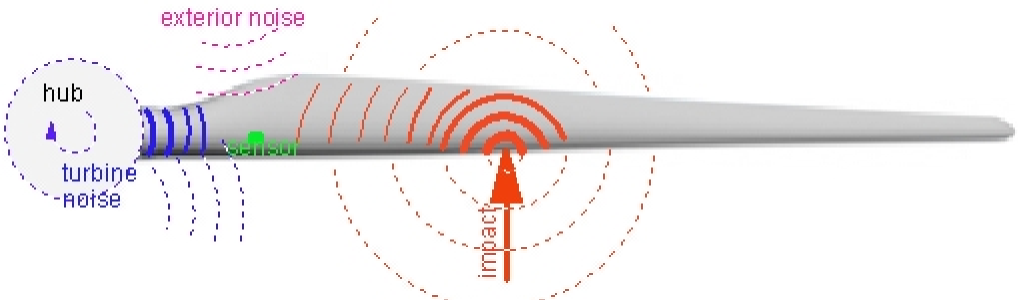

Figure 2: *Simplified illustration of the signals that reach an acoustic sensor in a blade.*

As a result from preliminary tests the optimal places for the sensors in the N80 turbine blades were found at the leading edge at a radius of 4m and 10m from the blade flange.

The system has two low-cost ICP acceleration sensors installed in each blade that detect the impact sound from a bird collision. These are connected to an industrial data-acquisition system in the hub with real-time signal processing, event-triggering algorithm and local storage capabilities.

A Wireless LAN link is used for transferring the data between the hub and the industrial host PC in the tower base and via a LAN network and ADSL to any remote location, see also Figure 4. All software applications can be controlled and reconfigured remotely during operation, for instance setting of trigger levels and modifying the sending list for email alerts.

In case of a trigger event the all data is automatically transferred to the PC, an email message is sent to the operator and storing video data on a permanent location.

To filter out the actual collision of a bird from all other types of noises, numerous recordings have been collected and characterized of all kind of noises that occur within a wind turbine:

- from the rotor (blade creaking, crack propagation, falling material, pitching)
- from the nacelle (tonal noises through gearbox, yawing, brakes, starts and stops)
- from external sources (lightning, precipitation, maintenance, sensor failures)

Figure 3 shows some examples of registered operating noises.

To discriminate between collisions and other events a number of different real-time signal processing techniques has been developed and implemented in a single measurement platform. For noises that have more or less the same characteristics as collisions, such as impulse sounds, it is of course the most difficult to discriminate, see also Table 1.

The applied data processing techniques have been tailored to the specific characteristics of both the noises and the collision signals, which are of course dependent on the operational state of the turbine, such as rotor speed and activity of the controls, but also of external conditions. The characteristics also differ per turbine type or possibly even per individual turbine. Therefore some tuning needs to be done in order to configure a system in a new type of turbine, such as optimal sensor locations and signal processing algorithms.

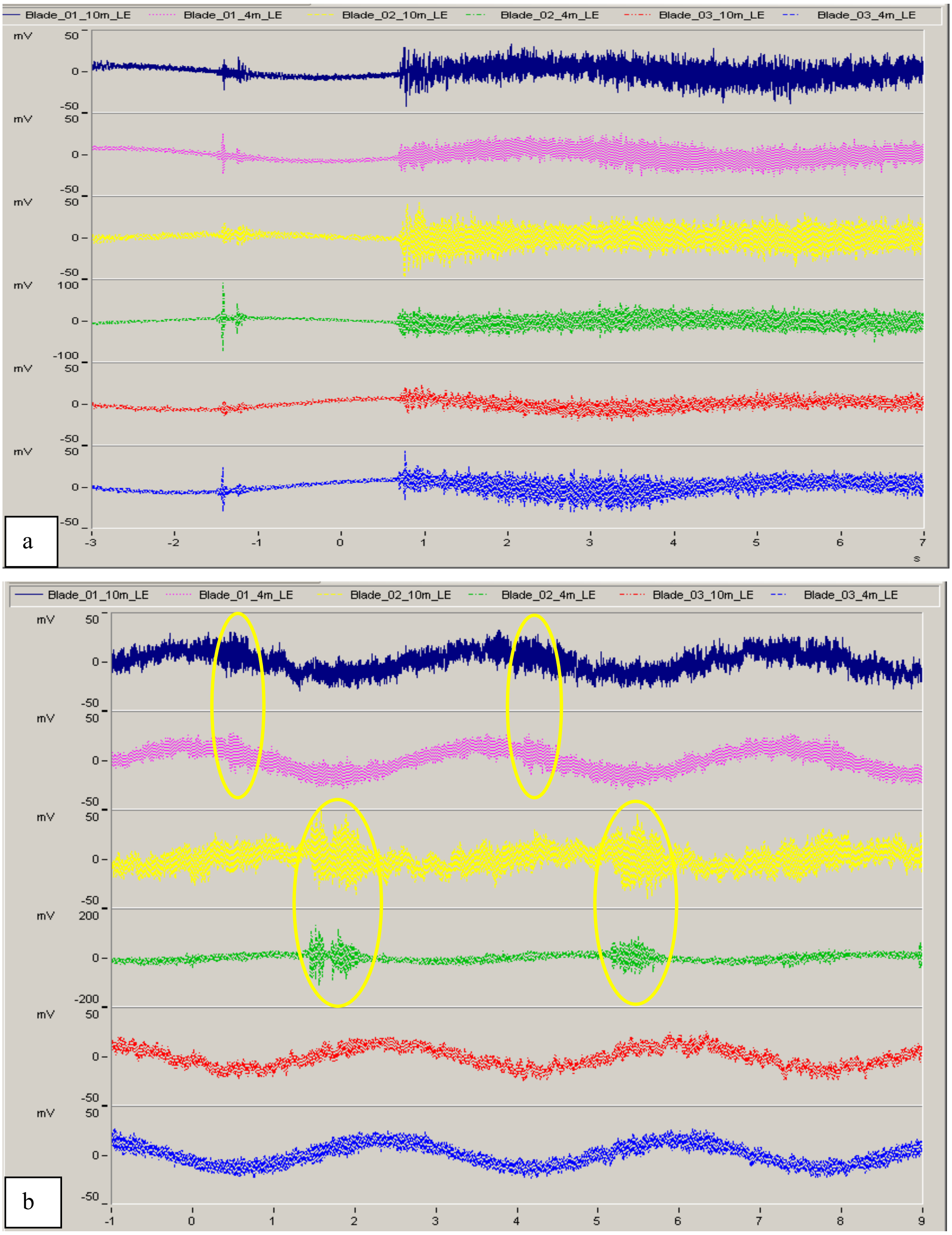

Figure 3: *Registration (a) during turbine stop procedure with drive-train impulses at -1.5 sec. and (b) of periodic creaking of blade 1 and 3 (marked by ellipses).*

Table 1: *Characterization of background noise and comparison with bird collision*

	Characteristic Description	Frequency content	Energy content	Duration	Envelope	Occurrence	Synchronicity blades
Nacelle	Tonal noise	<1kHz. Peaks	Medium	> 1 sec	Slowly varying	Permanent, if rotating	Yes
	Drive-train impulses	1.5-3kHz. Spread	High	1 - 20 ms	Impulses	Frequent	Yes, but ampl. & time differences
	Blade creaking	1.5-3kHz. Spread	High	< 1 sec	Impulses repeating	Frequent, if high winds	No
Rotor	Collective pitching (fast)	1-2kHz. Spread	High	> 1 sec	Step	Frequent	Yes
	Pitching (slow, fine adjustments)	1-2kHz. Spread	High	< 1 sec	Bursts, repeating	Frequent	Sometimes
	Yawing	1-2kHz. Spread	Low	> 1 sec	Step	Frequent	Yes
	Start / Stop	Spread+ Peaks <2k	High	> 1 sec	Step	Frequent	Yes
	Emergency Stop	Spread+ Peaks <2k	High	> 1 sec	Step	Rare	Yes
External	Precipitation	1.5-3kHz. Spread	Low	> 1 sec	Slowly varying	Sometimes	No (azimuth dependent)
	Lightning	Spread, mostly L.F.	High	> 1 sec	Impulses or varying	Rare	No (azimuth dependent)
	Maintenance (personnel, hand tools, drilling, hammering)	Spread	High	< 1 sec	Impulses	Rare	Sometimes
		Tonal <1k	High	> 1 sec	Varying		
	Sensor failures: - dead sensor	L.F./none	None	> 1 sec	None	Rare	No
	- spikes - ...	Spread	High	< 1 sec	Impulses	Rare	No (azimuth dependent?)
	Collision	**1-2kHz. Spread**	**High**	**5 - 20 ms**	**Impulse**	**Rare**	**No**

Processing	**Filtering**	**Masking trig.level**	**Fingerprint recognition**	**Manual evaluation**	**Time Masking**

Legend

Characteristic	Characteristics alike	Characteristics differ a little / sometimes	Characteristics differ significantly / always
Processing	Not applicable	Applicable, but not very effectively	Well applicable

2.5 Video registration

As a result of several field tests we have selected an industrial monochrome camera with fixed lens. Its main demonstrated features are: 1.45 Megapixel near-IR sensitive 2/3” CCD (Sony ICX285AL), full-frame streaming at 10.5 frames per second continuously with 8-bits colour depth setting. The camera uses a FireWire (IEEE1394a) interface with DCAM V1.3 standard software. The applied lens has a 60° fixed viewing angle and is IR-corrected.

The PC in the tower base, see Figure 4, controls all camera functions, such as image acquisition and exposure control. All images are continuously stored at a temporary location in hard disk for a user-defined time, e.g. 10 minutes. After a collision event the selected data is moved to a permanent location. The PC continuously determines the image brightness and contrast and controls the camera gain, shutter time and gamma setting as well as the lens iris.

During nighttime and other situations with poor visibility, additional measures like infrared lights are necessary to obtain images that are good enough for recognising the bird species. The current set up has four infrared LED lights (48W, 880nm, 30° beam width), which are invisible for both birds and humans, mounted at the tower below and three on the nacelle.

For testing purposes two different stainless steel camera housings are installed. Both housings are temperature-controlled against condensation or freezing and have a flat lens cover to prevent for the accumulation of water, snow and dirt. Both housings are equipped with a washer wiper unit. Due to technical problems with the washer pump and spray nozzles, we did not use these anymore. This did not affect the sight significantly, because of the inland turbine location.

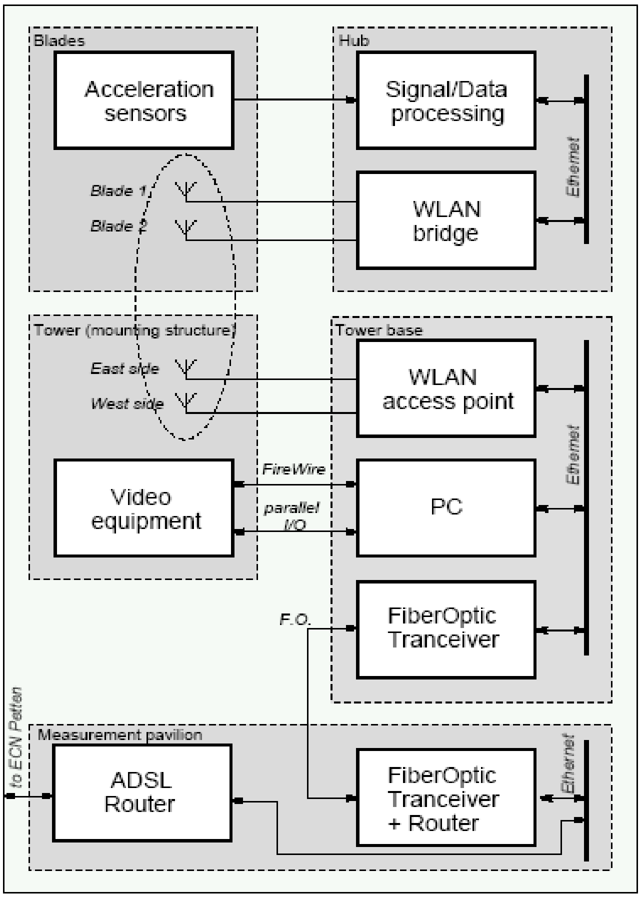

Figure 4: *Present data communication infrastructure for WT-Bird on the N80 at the ECN test site EWTW*

2.6 Prototype installation

All equipment outdoors is mounted on four identical tripods mounted at a height of 9 meters, about 1 meter from the tower wall. The total weight including equipment is about 100kg. Two steel cables, each forming a square, pull the tripods against the tower wall, so that the structure is fixed by friction. The height is chosen to resemble the relatively short tower of offshore turbines and also to prevent damage through vandalism. All equipment is low voltage. The installation of the outdoor equipment took one day. Figure 5 shows one of the cameras (a) and a pair of floodlights on the tripods (b) and the floodlights on top of the nacelle.

The rotor equipment consists of a steel cabinet in the hub and 6 sensors and 2 WLAN antennas in the blades. This equipment can also be installed within a day, if the mounting provisions in the hub are available.

Figure 5: *Outdoor equipment of the WT-Bird prototype on Nordex N80 turbine at EWTW*

3. Summary of results

By means of extensive testing, it has been demonstrated that the WT-Bird system meets the following requirements.

Bird Impact Detection
Small birds with a weight of say 50 grams can be detected in most of the cases. Shooting tennis balls of 50 grams against rotating rotor blades has proved this. A fraction of 40% of the hits indeed led to a trigger. Another 20% of the hits were falsely identified as blade noise, but this can easily be solved in the signal processing. Although the remaining 40% gave a sound signal that was clearly noticeable, it was below the trigger level, which was adjusted to the background noise level of the N80. Therefore it is very likely that the fraction of hits leading to a trigger is much higher for larger birds.

Recognition of Bird species
The tennis balls of 6.5 cm in diameter, representing dummy birds with a wingspan of approximately 10 cm, could easily be observed by the video camera during the daytime, see also Figure 6. The frame rate of 10.5 frames per second (FPS) is sufficient to record the flight track of the dummies. Flap frequencies up to 5Hz. can be measured, which is assumed to be enough for the majority of the abundant bird species. Figure 7 shows a series of images of a passing bird. The frame-rate is also sufficient to measure the impact location. With two cameras only a small percentage (about 10%) of the rotor swept area is outside of the camera view. With only one camera mounted on the side of the main wind direction the majority of the impacts can still be located.
Under a wide variety of lighting conditions very stable video images have been obtained with only minimal motion smear. The image quality was only affected a little by rainfall. Hail, snow and fog are expected to hinder the species recognition significantly, but no recordings are available at the moment to quantify this. Figure 8 to Figure 11 show some examples of different lighting conditions.
Despite the installed infrared lights, the camera's signal-to-noise ratio is still insufficient for species recognition at nighttime. During low-light conditions, but not complete darkness, the contrast is only sufficient for recognition of larger birds, say 50cm wingspan, or of birds at short distances up to about 20m.

Storage of Triggers and Video Recordings
The data from a trigger event is stored on a flash disc in the measurement device in the hub. It can store data of at least 100 trigger events, which safeguards the data in case of a network loss.
The live video registrations are stored on a temporary location on the hard drive of the host PC. New files are generated each minute with names that contain the camera serial number and a timestamp. After a trigger event any file that contains images in the period between 20 sec. before to 20 sec. after the event is moved to a permanent location. All files older than 10 minutes are deleted. The user can modify these timing settings remotely.
After an event has been recorded, an alert email message is sent to the operator. The messages contain turbine identification, date and time of the event, current trigger levels, trigger serial number (counter) and the sensors that caused the event. The recordings and other event data can be downloaded on request for further analysis and backup.

Hardware and Reliability
The system is designed as such that it can be installed on any turbine as long as power supply is available in the hub and proper sensor locations are available. The system is developed for both onshore and offshore applications. Endurance tests have shown that the system runs continuously without major problems; only teething troubles had to be solved.

Extended tests are planned to investigate the operation at coastal and offshore locations.
In addition to the detection of collisions and recognition birds species the WT-Bird system could serve other functions. Some additional functions, either already present or optional, are discussed briefly.

Additional functionalities: Blade monitoring
After a lightning strike hit a blade tip in November 2005 the damage could be inspected in detail from the recorded video images, which is shown in Figure 12. Therefore the assessment of visible blade damage from other causes is also possible.

Blade monitoring by means of the applied acceleration sensors is an interesting option. The sensors and the measuring equipment of the WT-Bird system already provide high-frequency acquisition with a wide dynamic range. The developed real-time signal-processing algorithm already identifies cracks or creaking of the blades. The measurement system has other algorithms available for class counting, equivalent loads or trending, whichever is applicable for additional analysis. As another option special triggering events for large cracks could be developed.
Currently the WT-Bird system automatically performs a regular self-test, currently every 24 hours, by simulating a collision event. This is implemented by programmatically releasing the trigger, causing the same actions as after a real collision event. The only difference is the email header, which includes "simulated collision". The stored sound recordings over time can already give some indication of different behaviour of the blade or the pitch mechanism.

As the acceleration sensors also register low-frequency signals, including the rotational frequency, the blade bending due to gravity is observed as well as some higher order edgewise blade oscillations. The latter depends on the oscillation mode in combination with the sensor location. By analysing the trends in oscillation amplitude and frequency some indications on blade ageing could be found. This can already be monitored manually, as regular samples of the blade sensors are collected. However dedicated signal analysis is necessary for automated blade monitoring.

Additional functionalities: Assessment of abundant bird species and flight behaviour
In the current configuration the majority of the video images are deleted, as no trigger has occurred. By implementing automatic image analysis on the host PC the presence of small moving objects like birds could be detected. Then, after some waiting time to assure that no collision was detected, these images can be stored on a permanent location, other than the location for the collision events. One should be aware of the large amount of data that may be stored then, as one hour of video for a single camera is already over 50GB. Therefore not only efficient data compression is required, but also large local storage devices and high-speed data transfer.
Obviously, the limitations of the video system as discussed above apply and furthermore the field of view is extremely small compared to other observation methods.

Additional functionalities: Intruder detection
Intruder detection is not possible in the current set up as the camera field of view is upwards. Of course additional cameras can be installed, but for this application standard solutions with a video security system or radar are more suitable.

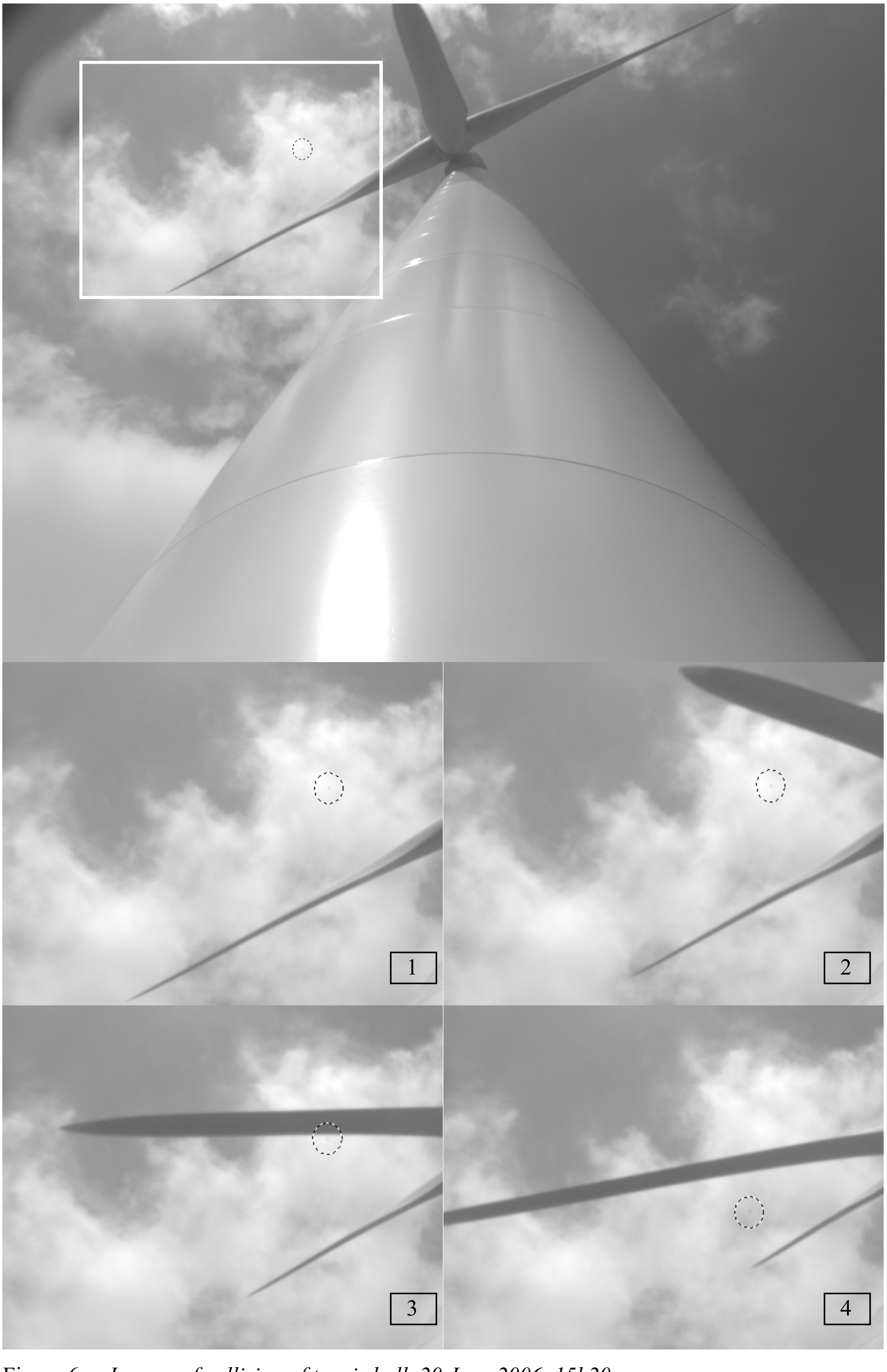

Figure 6: *Images of collision of tennis ball, 20 June 2006, 15h20*

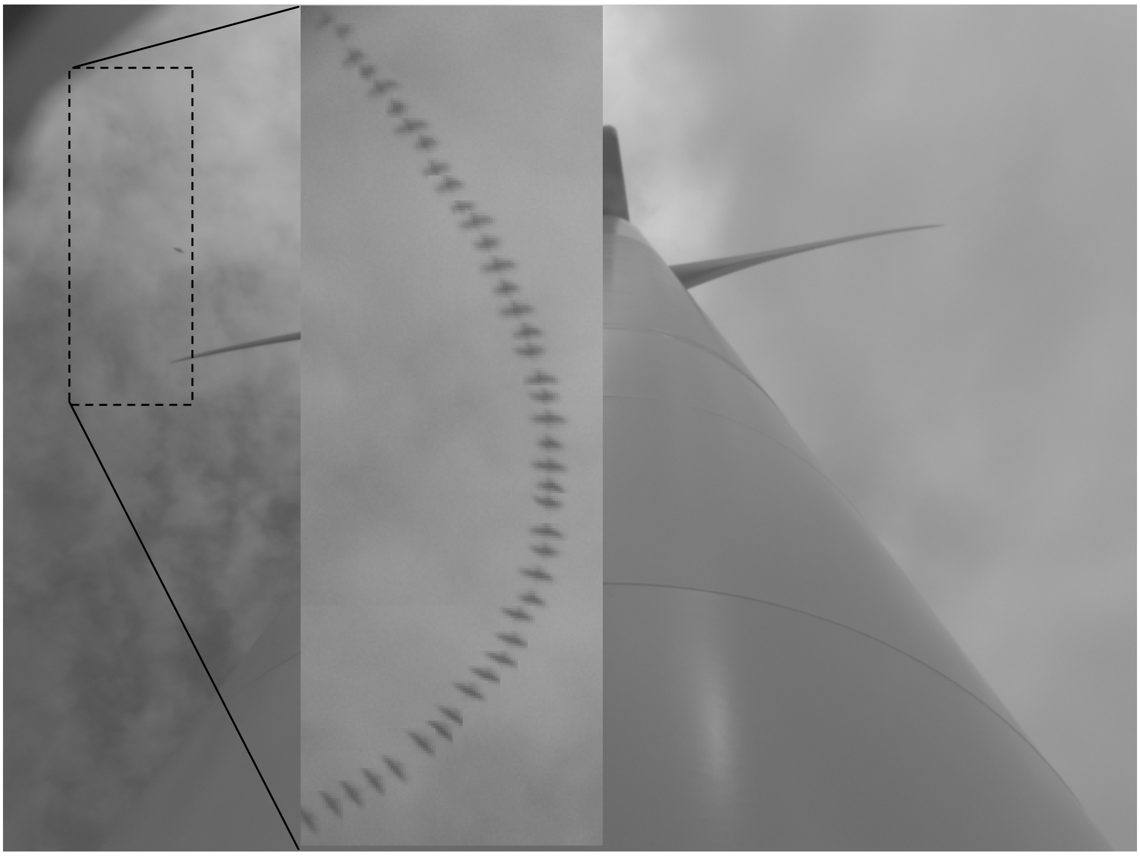

Figure 7: *Images of passing bird, 2 June 2006, 13h09*

Figure 8: *Image on bright day with high contrast differences, 20 June 2006, 15h26*

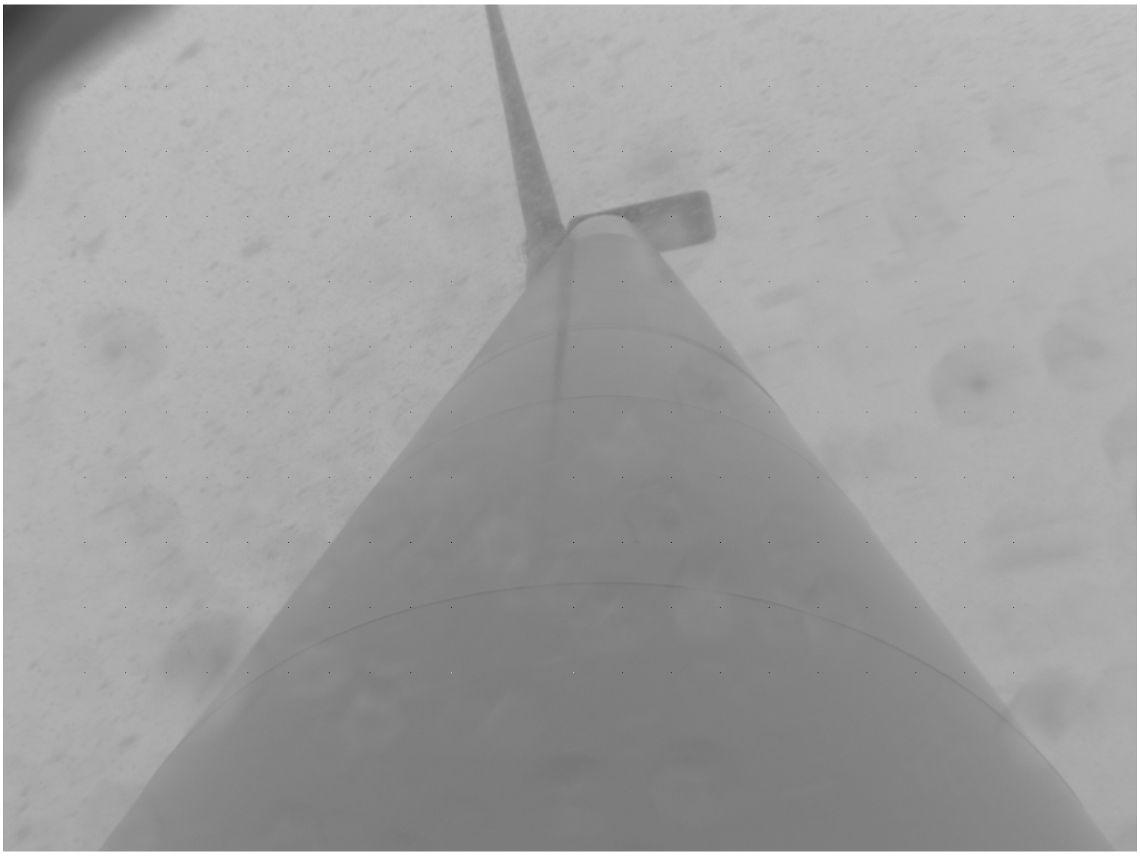

Figure 9: *Image during snowfall, 29 Dec 2005, 14h51*

Figure 10: *Image during complete darkness, 20 Feb 2006, 19h03*

Figure 11: *Image at low-light conditions, 2 June 2006, 22h59*

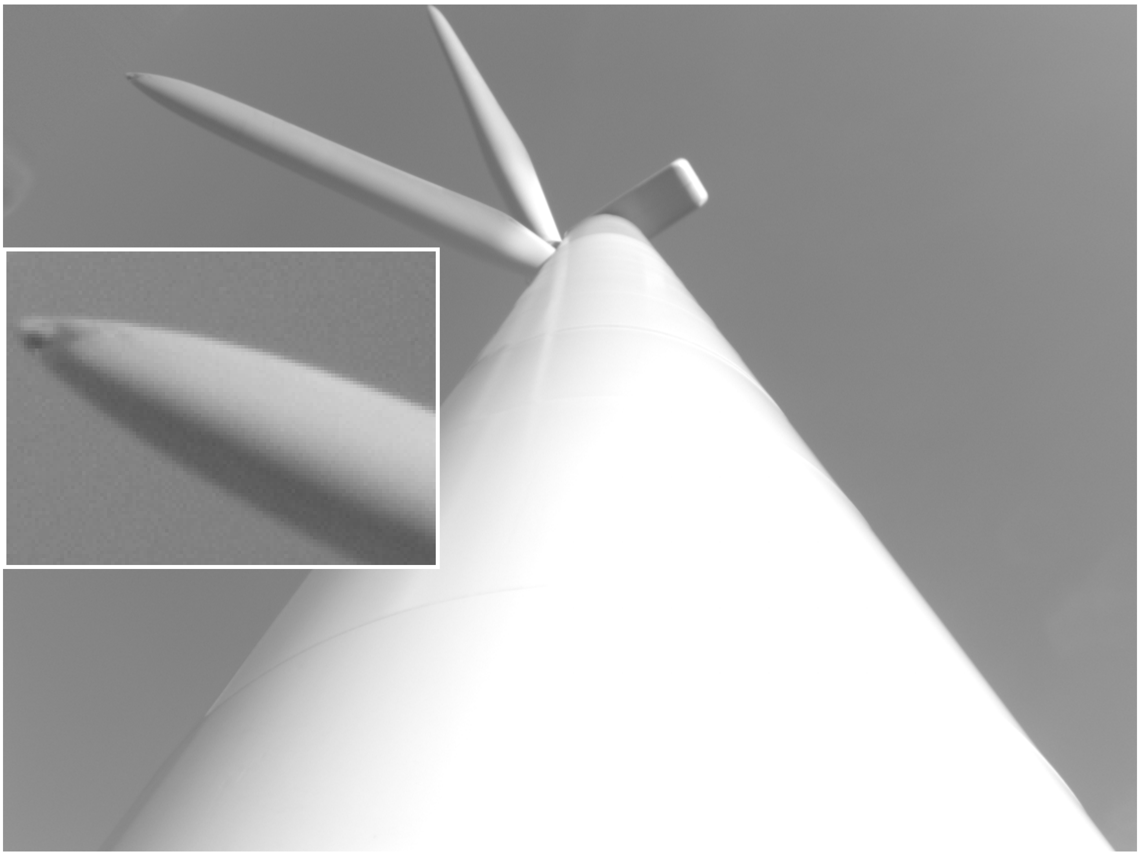

Figure 12: Image of lightning damage showing hole and de-lamination, 19 Nov 2005, 09h00