Monitoring of bird collisions in wind farm under offshore-like conditions using WT-BIRD system

Final report

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ECN-E--09-033 OCTOBER 2010

Acknowledgement/Preface

This project was partly funded under the We@Sea program under project 2004-029.

Abstract

At present monitoring of bird collisions with wind turbines is only possible for land-based turbines. Current methods are labour intensive and therefore monitoring can only take place at a small scale. A prototype of a monitoring system that counts actual collisions and stores video registrations for species recognition has been developed by ECN and tested successfully at a 2.5 MW land-based turbine.

For application offshore a series of tests was planned in a coastal wind farm located on the Oosterschelde Storm Flood Barrier in order to test and calibrate the monitoring system in offshore-like conditions. However these tests could not start, because of warranty discussions with the wind turbine manufacturer. So far no suitable alternative locations have been found, so it is not foreseen that other installations will take place within the term of We@Sea.

In this project ECN has continued the monitoring with the current prototype. In general the system has shown to be reliable. In the monitoring period one bird collision has been recorded and also a number of other events. Tests with several novel camera types showed that the image quality at night can be improved considerably, but still not sufficiently to recognize birds in full darkness.

This report contains the status of the WT-Bird development and the progress and results of the project with the original and more ambitious planning.

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Summary

At present monitoring of bird collisions with wind turbines is only possible for land-based turbines. Current methods are labour intensive and therefore monitoring can only take place at a small scale. There is a clear need for cost-effective methods that can also be applied offshore and on a larger scale over a long period of time. A prototype of a monitoring system that counts actual collisions and stores video registrations for species recognition has been developed by ECN and tested successfully at a 2.5 MW land-based turbine.

For application offshore a series of tests was planned in a coastal wind farm located on the Oosterschelde Storm Flood Barrier in order to test and calibrate the monitoring system in offshore-like conditions and with bird species that are more representative. However these tests could not start, because of warranty discussions with the wind turbine manufacturer

Therefore ECN and E-Connection have sought for alternative locations that are also representative for offshore farms and with significant numbers of bird casualties, but have not been successful in this. In November 2008 NoordzeeWind, Vestas and ECN have started to investigate the possibilities for retrofit installation of WT-Bird on one or more turbines in the NSW offshore wind farm. As the preparations for offshore application will take considerable time, it is not foreseen that the installation will take place within the term of We@Sea and thus cannot be reported here.

The original project objective was to have a calibrated monitoring system suitable for offshore application, proven by tests in representative conditions. In general this objective could not be met, while for the planned tests at the Oosterschelde Storm Flood Barrier no concrete results, such as installations or even test results could be delivered. A concrete result of the preparations for a monitoring campaign at the planned location and at alternative locations is a generic plan for the set up of a monitoring campaign.

As an additional task ECN has continued the monitoring with the current prototype at the ECN Wind Turbine test site Wieringermeer, which has provided valuable operational experience with the system itself, e.g. on reliability and maintenance, as well as with analysis of collisions and other events. In general the system has shown to be reliable with only little maintenance effort. In the monitoring period one bird collisions has been recorded and also a number of other events.

Because of rapid product developments several novel camera types could were available showing considerable improvement of the image quality at night. This improved image quality, however, it is still not sufficient to recognize birds in full darkness.

Finally, because of presentations and contacts with several parties, such as developers, wind farm owners, etc. we have made them better acquainted with the WT-Bird system and its capabilities. Furthermore this has lead to some promising new opportunities to install en apply the WT-Bird system.

1. Introduction

At present monitoring of bird collisions is only possible for land-based turbines. Current methods are labour intensive and therefore monitoring can only take place at a small scale. There is a clear need for cost-effective methods that can also be applied offshore and on a larger scale and over a longer period of time, see also [2] and [3].

1.1 Development history of WT-Bird prototype

For several years ECN has been developing the so-called WT-Bird® system[1]. It counts actual collisions and stores video registrations, which can be used for species recognition. Field tests on small land-based turbines in 2004 have shown the proof of principle of the complete system [1]. With this system for automated detection and registration of bird collisions it should be possible to carry out cost-effective monitoring at a larger scale for both onshore and offshore wind farms.

Within the SenterNovem funded project (nr. 2020-03-11-10-003) this WT-Bird system has been developed for application on multi-megawatt offshore turbines. In this project ECN co-operated with Alterra and Bureau Waardenburg BV, E-Connection Project BV and NUON. The project plan included a technical evaluation for 6 months of the system on a single turbine on the mainland at the ECN Wind Turbine test site Wieringermeer [4], [5], [6].

1.2 WT-Bird prototype description

The basic idea behind WT-Bird is that collisions cause vibrations in the wind turbine structure, e.g. in the blades or the tower, that can be measured by acoustical vibration sensors. These raw measurements are processed in order to cancel out any disturbances, such as turbine operational noise, that may cause false trigger events, see also the overview in Appendix A.

In case of a collision a trigger event is generated, causing that:

- the collision is registered (date-time, location, classification of event, count nr., …);
- the video images before and after the collision are stored;
- the sound recordings before and after the collision are stored;
- an e-mail message is sent to the remote operator together with all data above.

The operator has to analyze the video and audio recordings in order to:

- check whether a collision took place or not, in case of doubt;
- identify species;
- analyze the collision mechanism, e.g. blade position, bird movement before collision;
- take notice of special circumstances, e.g. weather, other birds passing, etc.

Other available system features are:

- independent operation from wind farm, except for 230V mains connection and network connection to shore;
- robust for short power interruptions;
- possibility to add functionality to monitor other events, such as lightning strikes, visible and audible damage, intruders or bird movements;
- frequent self-checks and automatic logging of all starts and stops, so that the availability over a long period of time is known exactly;
- modular set-up using standardized digital network communication, so that the type, number and location of vibration sensors and cameras can be adjusted to the needs of the application;
- only standard industrial components are used (proven technology).

[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.

1.3 Results from field tests in the Wieringermeer

During a field test on a single onshore wind turbine only a small number of bird collisions was detected, probably because this is not a typical concentrated bird migration route. These results have been very useful to demonstrate the capabilities of the monitoring system, but the numbers were too small to calibrate the monitoring system. Moreover, the birds on these sites are typical land birds so not representative for the birds at offshore wind farms. Also the environment is not representative for turbines located offshore.

Despite this, the prototype in the Wieringermeer has been kept operational during this project in order to gain experience and to leave open the possibility to carry out experiments or improvements that can be useful for offshore application. These field test results are described in more detail in section 3.2.

1.4 Necessary steps towards offshore application

Before this monitoring system can be applied in offshore wind farms it should be evaluated and optimized in a wind farm with multi-megawatt wind turbines in offshore-comparable conditions and with presence of bird species typical for offshore sites. The best test solution would be a real offshore wind turbine, but that would mean that we would lose the opportunity to search each morning for dead birds around this turbine. These field searches are an essential element to prove that WT-BIRD has really counted all bird collisions.

Therefore it has been proposed to test WT-BIRD at the wind turbines at Roggenplaat, Neeltje-Jans or Jacobahaven at the Oosterschelde storm flood barrier in Zeeland.

The abundant bird species at these sites are coastal birds and also concentrated bird migration occurs over these sites. These wind farms also offer the opportunity that daily field searches can be carried out each morning, necessary to check the efficiency of WT-BIRD.

Field investigations have shown relative high numbers of bird casualties, so these wind turbines offer a much better opportunity for WT-BIRD to really detect multiple bird collisions.

1.5 Project objectives and contribution to We@Sea program

The project objectives are fourfold:

1. Evaluate reliability and performance of WT-BIRD system under offshore conditions;
2. Test and improve WT-BIRD system configuration with respect to performance, costs and corrosion resistance for offshore-like conditions;
3. Obtain 1-year of monitoring data from a wind farm with relatively high numbers of fatalities;
4. Set-up a plan for an offshore monitoring campaign.

The project, which is part of the We@Sea research line 2.4 “Challenges for nature”, serves to contribute to:

1. the development of cost effective monitoring methods for bird collisions at offshore wind turbines;
2. the assessment of the size and scale of the impacts and relation to wind farm design and construction.

1.6 Original Project set-up

The approach of this project is to set up and execute a 1-year monitoring campaign in a wind farm at Vluchthavendam Neeltje-Jans Buitenhaven, Havendam Roompotsluis, Roggenplaat or Jacobahaven at the Oosterschelde storm flood barrier. The WT-BIRD systems that will be installed there are exposed to offshore conditions in respect to wind, background-noise and corrosion.

One of the major problems for testing WT-BIRD with real bird collisions is the low number of bird collisions at most wind turbines on-shore. Long lasting daily field-investigations including a predation-test ('vindkansproef') have been carried out under responsibility of bird expert Baptist. These investigations have shown a relative high number of bird collisions of 2 bird casualties per wind turbine per year at wind farm Jacobahaven and 7 bird casualties per wind turbine per year at wind farm Roggenplaat.

Several wind turbine locations of the wind parks at Neeltje-Jans harbour dams, Roggenplaat and Jacobahaven are also suited for field research by an ornithologist.

By comparing several different configurations of the WT-BIRD system, optimization can take place within a relatively short time.

While the finalised SenterNovem project was focused on the technical development and evaluation of the first prototype for offshore-scale wind turbines, this project is focused on the offshore application. For this not only an extended technical evaluation is needed, but also the development and evaluation of the methodology: choice of configuration, calibration, operation and maintenance needs, presentation and analysis of data, etc.

Project structure:

Task 1: Preparation of monitoring campaign

Task 2: Installation

Task 3: Data evaluation

Task 4: System optimization

Task 5: Reporting

Main results:

1. Monitoring system that is reliable in offshore weather conditions.
2. Description of a monitoring method for offshore wind farms
3. Calibrated monitoring data over 1-year period of wind farm at near-shore location.

2. Project activities

In this chapter the project activities have been described and motivated. First the developments related to the preparation of the monitoring campaign at the Oosterschelde Storm Flood Barrier are mentioned in more or less chronological order.

2.1 Preparation of monitoring campaign wind farm of E-Connection Project at the Oosterschelde Storm Flood Barrier

2.1.1 Overview of developments

In the course of the project, which started on 01-05-2005, the realization of the wind parks at the Oosterschelde Storm Flood Barrier has been delayed considerably. At the time of the original final date of the project the wind farm was still not yet commissioned. Starting with preparing the monitoring campaign before the farm had been commissioned was blocked by warranty discussions with the wind turbine manufacturer. In the meantime ECP and ECN carried out the following activities for preparation:

- Meetings between ECN and ECP to discuss possibilities with V90 turbines, possible alternatives, planning and organisation;
- Frequent contact with ECP to update status of the planning and realization of the park;
- Contacts between ECP with the wind farm owners and Vestas in order to obtain permission and support for the monitoring campaign;
- Contacts with Vestas by ECP to discuss possibilities for installation and planning issues;
- Contacts with Vestas by ECN to supply information on system and installation requirements.

As stated, ECN has also directly contacted Vestas NL and Vestas DK to discuss possibilities for application of WT-Bird on the Vestas V90 turbine, both in the wind farm Oosterscheldekering and elsewhere. However, these initiatives did also not lead to any progress towards application, i.e. Vestas was not willing to allow and co-operate with installation of the monitoring systems. Therefore ECN started to look for alternative locations to realise a monitoring within this project, which is described in the subsection 2.2. Further preparations related to the wind farm at the Oosterscheldekering were set on hold.

2.2 Search for alternative wind farm locations

2.2.1 Wind farm Roggenplaat

When the problems with the application on the V90 turbines arose, ECP offered to start monitoring at their Enercon E33 turbines at Roggenplaat. Because of the coastal location of this wind farm as well as the track record on bird research it is very suitable for testing the WT-Bird system. However, because of the small scale of the wind turbine and the need to install an independent power supply in the rotor (no power available in the rotor), ECN decided not to start monitoring on these turbines.

2.2.2 Search for alternative wind farm locations

In October 2006 ECN sent a mailing to a number of project developers, wind farm owners and wind turbine manufacturers to find possibilities to evaluate the WT-Bird system at other locations. Also a number of parties contacted ECN to request information on WT-Bird.

With some of these parties the information exchange was more intensive, such as specific offers that were sent to several parties.

In the Netherlands 10 developers/owners have been contacted and also 10 others in 8 European and 1 non-European country. However, none of these did result in a possibility to start a monitoring campaign.

2.2.3 Wind farm OWEZ

In November 2008 ECN was invited to present the current status of WT-Bird in order to evaluate whether WT-Bird can be applied on the OWEZ wind farm within MEP-NSW framework.
For this reason the project was not immediately stopped in 2008. As a result NoordzeeWind has organised several meetings with both Vestas and ECN and preparations have started to determine whether and how application of the WT-Bird system in OWEZ can be realized. A test and development plan has been defined, starting with a series of tests for the triggering system on a single blade on the ground. Only when these tests are successful the next series of tests - registration of turbine operational noise - will start. As these preparations will take considerable time, it is not foreseen that offshore application can be realized within the term of We@Sea. Therefore it was decided after all to round off the projects final report and to end the project.

2.3 Continuation of monitoring with current prototype

During this project ECN has continued the monitoring with the current prototype at the ECN test field in the Wieringermeer. This was to gain more operational experience as well as to demonstrate the system to potential customers. This holds checking and analyzing incoming events (e.g. possible collisions) as well as maintaining the system.

Another purpose for continuation with the current prototype is to test improvements or modifications that are required for application at other locations and other wind turbine types. For example, we have tested several novel camera types in order to improve the image quality at night.

2.4 Project extension

Also an extension of the project end date with one year to 28-02-2008 was requested in order to find these alternative locations and possibly realise a monitoring campaign. Around the postponed final date continuation of the project was again discussed with the We@Sea program management and it was decided not to stop the project yet, as several initiatives for alternative locations were ongoing. As in January 2009 still no concrete opportunities for monitoring were known, it was decided to write the final report and to stop all further project activities.

3. Project results

3.1 Generic plan for monitoring campaign

In order to prepare the planned monitoring campaign, but also on request of several wind farm owners and other parties, a generic monitoring plan has been defined, see Appendix D. This plan has a similar structure as the standardised measurement campaigns that ECN performs on a regular basis, merely as input for wind turbine prototype certification. It includes generic conditions, preparation and installation, measurement, reporting and dismantling.

A number of technical and organisational issues in this plan need to be elaborated on further, as these are not yet well known and/or are specific to the wind farm.

For preparing the installation on other wind turbine types than the Nordex N80, separate tests have been described to find suitable locations in the blades for the acoustical sensors and to characterize the impacts using dummies.

3.2 Operational experience with current prototype at ECN test field

3.2.1 Operational experience, maintenance activities

The prototype system proved to be reliable and low maintenance, but still several improvements are proposed for the current prototype:

- The industrial PC that is currently used has experienced several problems related to hardware. For new applications it is advised to apply an upgraded industrial PC.
- The mechanical construction of the two directional WLAN antennas failed after 1 and 3 years of operation. After the second antenna failed both antennas have been replaced. The construction of the two new antennas has been strengthened. For offshore the alternative location of the WLAN antennas in the nacelle, as used currently in the OWEZ load measurement campaign, is preferred.
- Use integral sensor cables through the blades. Now cables with extensions have been applied, which can be a cause of defect. After 3 years of operation 2 out of 6 sensor cables have failed. It is also useful to look for improvement of the flexible link from the blade bulkhead to the hub.
- Re-engineering of the washer/wiper installation (only required offshore)
- Replace AVT Dolphin F-145 B cameras (discontinued) by newer type Pike F-145 B/Fiber, which is fully compatible (only for new applications), see also test results in section 3.2.3.
- Replace IMC Cronos PL/2 measurement platform (discontinued) by newer type IMC Cronos SL, which is fully compatible (only for new applications)
- A number of possible improvements of the software are identified:
    - add hyperlinks in e-mail messages to directly access audio/video files
    - add exact timing of impact event to email messages (now time delay is about 15 sec.)
    - send e-mail when a defect occurs, e.g. lost connection and reconnection
    - apply lossless compression of video data within camera (possible with Pike camera type in combination with new firmware and driver software)
    - automated (lossless) conversion of the audio/video files to current audio/video formats, e.g. wav, avi/mpeg-2/wmv.

3.2.2 Detected collisions and other events

During the monitoring period a several events were recorded, including at least one bird collisions, see also Table 1. Sound and video fragments of each listed event are made available on the enclosed DVD and selected images are printed in 0.

Table 1: List of events that were detected and registered

Type of event	Date/time	Description
Collision 0, Figure 1 and Figure 2	2008-04-25 16:14	Clear collision, although the moment of impact was not registered due to tower shadow, because only one camera was running. Collision event was not directly recognised by the operator, because of temporary loss of contact with the measurement PC.
Ice falling off rotor (probably) or bird collision (possibly) 0, Figure 3	2007-02-07 13:02	Several falling objects can be detected. Images are not clear enough to recognise falling ice or birds. For security field searches have been undertaken shortly after the event, but no bird casualties were found.
Ice falling off rotor 0, Figure 4 and Figure 5	2007-03-19 10:20-10:26, 11:08	On 2007-03-19 10:20 and 10:26 both the sounds and images are clearly distinct from a bird collision. For 2007-03-19 11:08 an ice sheet seems to hit the rotor blade, which sounds like a bird collision. Only after detailed study of the images the event was (also) identified as ice falling off. For 2007-02-08 00:30 only the sound indicates ice falling off.
Ice falling off rotor	2007-02-08 00:30	
Lightning nearby	2007-06-08 01:03	Images do not show whether it was a direct lightning impact and at which location it stroke
Lightning 0, Figure 6	2007-03-21 01:02	Static loading of the acceleration sensors caused that the measurement system needed recovery for several minutes, but no damage occurred.
Loose object in blade	2007-02-19 14:12 and 2007-02-24 07:18	The cause of the trigger is directly clear from the sound from the two sensors in the blade

From these few collision events a number a number of things could be observed.

- The silhouette of the bird before it collides on 2008-04-25 is clearly visible, showing that the camera resolution is sufficient. The number of pixels (h x v) is 1392 x 1040 and with the chosen focal length of the lens 1 pixel covers an area of about 5 x 5 cm at hub height.
- The bird more or less glides towards the turbine only flapping its wings a few times. With the frame rate of 11 FPS the frequency of the wind flap frequency of this bird can be determined.
- The flying path of the bird, which is downwind of the rotor, shows slight periodic curves. It looks like this is because of the influence of the rotor wake.
- Under unfavourable weather conditions, e.g. rain, fog and semi-darkness, the contrast is insufficient to provide a clear picture of the bird for species recognition. This is clear from the collision on 2007-02-07. However the object can still be seen, so that the occurrence of a bird collision can be confirmed.
- It seems that collisions near the hub of large turbines are not (immediately) fatal, because of the relatively low speed of the blade section and the large shape of the blade. This is an argument for calibration of the monitoring system by ornithologists.
- Although other events, including turbine some activities, such as emergency stops and maintenance, can release the triggering of the system, these events can easily be identified.

Clearly the number of events is insufficient to evaluate the performance of the system in terms of the percentage of bird collisions that is actually detected and registered.

3.2.3 Nightly tests with new cameras

As the image quality of the current type of camera (AVT Dolphin F145-B) at night is insufficient to register birds, several alternative camera types have been tested in the field at night. Brief descriptions of all three tests are included here and selected images are available on the enclosed DVD and selected images are printed in Appendix B.2. The selected shutter time of the images is 82msec. unless specified otherwise.

In February 2006 and June 2006 an AVT Dolphin F145-B from a newer production series was tested in parallel with the already installed AVT Dolphin cameras. The problem of the high disturbance level of the current cameras (of the same type) that was reported by ECN level had been acknowledged by the manufacturer. The electronics had been improved, resulting in a significant reduction of the noise level, see also Appendix B.2, fig. 1. Because the new camera was positioned on the ground also the infrared lights are visible in the image.

During the same test a more expensive camera (Q-Imaging Retiga RET-EXI-F-M-12 without IR-filter, with Kodak 4Mpixel CCD) was tested, which is optimized for low-lighting conditions. The camera also has a Peltier cooling on the CCD sensor, but this feature is of no use as the small shutter times that are applied are too short (typically less than 100msec.) However this leads to a more complicated design, i.e. the camera uses a small internal fan for cooling of the housing, which is unfavourable for long-term outdoor exposure at remote locations. The camera showed superior image quality during low-lighting conditions, see Appendix B.2, fig. 2, but the IR response of this CCD was too low (as expected) to obtain sufficient image quality during complete darkness.

In July 2006 a nightly test was performed with the Q-Imaging Retiga-SRVwith Sony ICX285AL CCD (same as in the AVT Dolphin camera), with a better near-infrared sensitivity than the Kodak CCD. This camera has also low-noise electronics and a Peltier cooled CCD. The problem with this camera is that the maximum gain setting was too low to obtain images of sufficient quality in complete darkness.

Another camera type, which was not tested (Q-Imaging Rolera EMCCD camera), uses a so-called EMCCD sensor, which has an on-chip charge multiplier, programmable between 1x and 10x. This proved to enhance the contrast dramatically with only a small increase in the noise level when this was tested previously with an analogue camera. A drawback of this camera type is the low resolution (512 x 512 pixels) and the complexity of the camera, because of the CCD cooling, and a large housing with fan. This new EMCCD technology is most promising for our application, however only the sensor resolution is limited and also it is only available for a few camera types.

In January 2007 the newly developed AVT Pike F145-B/Fiber was tested at EWTW. As the AVT Dolphin series has been phased out at the end of 2008 this type, which is fully compatible, is to be applied instead.
Compared to the Dolphin camera the noise level has been reduced, i.e. no deterministic disturbances were visible, only thermal noise, which results in significant improvement of the image quality. However the image quality in full darkness is still insufficient to identify birds in the rotor plane, see also Appendix B.2, figure 3.
The data communication bus (IEEE 1394-B) can handle twice the bit rate of the previous bus (IEEE 1394-B) of the Dolphin camera. The new option of fibre-optic communication has been chosen, as this enables communication over long distances without the necessity for repeaters and without electromagnetic interference. Thirdly, the camera can be programmed to send compressed images and also AVI-format video, so that the transfer load is reduced and post-processing of images can be facilitated.

In October 2007 the JAI 1327GE camera was tested. Its sensor specifications and settings that could be applied are comparable to the current AVT Dolphin camera. The main purpose was not only to test its optical capabilities, but also to gain experience with the Gigabit Ethernet communication (GigE-Vision standard). This type of communication is cheaper than FireWire hardware and can be used up to 100m distance. It also seems to be more flexible regarding configuration and will probably develop further and become a widely used standard for communication with video equipment. Although the optical performance was not as good as the current cameras, the camera configuration and data communication showed to be suitable for our application.

3.3 Dissemination

Several presentations were held and publications were issued, see Appendix C.
Also a number of information requests were handled.

4. Conclusions and Recommendations

General:
- The proposed monitoring campaign is still a necessary step to test, improve and calibrate the monitoring system for offshore application.
- Agreement on the elaborated work plan with a clear commitment of each partner that is involved before the start of the activities is essential.

Operational experience with current prototype:
- The system proved to be reliable and low maintenance, but still several improvements are proposed for new applications of WT-Bird systems.
- One bird collision has been detected and registered, among a number of other events. Clearly this is insufficient to calibrate the system.
- Although the tested new camera types show significant improvement of the image quality, it is still insufficient to recognize birds during complete darkness.

New applications:
- Different blade designs require preparatory tests to determine optimal sensor locations.
- Mounting of outdoor equipment offshore requires a redesign of the mounting structures.
- A number of technical and organisational issues in the generic monitoring plan still need to be elaborated.

Dissemination:
- After several presentations, the launch of the webpage and the mailings to a number of parties, the WT-Bird system is widely known and considered to be a promising method for monitoring of bird collisions at remote locations, including offshore.

Project results:
- The original project objective was to have a calibrated monitoring system suitable for offshore application, proven by tests in representative conditions. In general this objective could not be met, while for the planned tests at the Oosterschelde Storm Flood Barrier no concrete results, such as installations or even test results could be delivered.
- A result of the preparations for a monitoring campaign at the planned location and at alternative locations is a generic plan for the set up of a monitoring campaign.
- As an additional task ECN has continued the monitoring with the current prototype at the ECN Wind Turbine test site Wieringermeer, which has provided valuable operational experience with the system itself, e.g. on reliability, maintenance, analysis of collisions and other events and possible improvements, e.g. novel camera types.
- Finally, because of presentations and contacts with several parties, such as developers, wind farm owners, etc. we have made them better acquainted with the WT-Bird system and its capabilities.

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Appendix A Overview of WT-Bird monitoring system

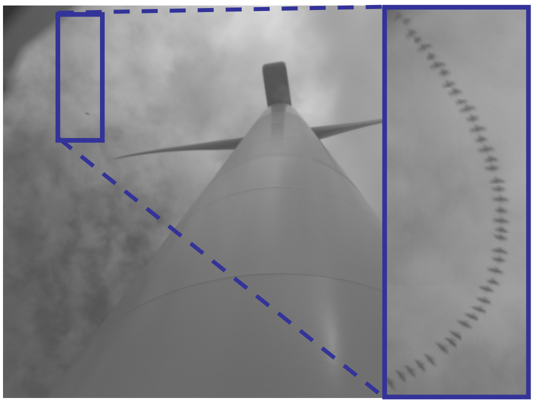
Background
The effects of wind turbines on birds have been studied extensively, mainly by visual observation and radar. This has provided a good insight in the collision risks for several land-based wind farms. However these methods are labour-intensive and therefore expensive. To assess the collision risks at a broader geographical scale there is a great need for more data of actual collision rates, in particular for offshore wind farms, where no applicable monitoring techniques are available.

Video equipment WT-Bird system on Nordex N80

WT-Bird description
A new method for continuous remote detection and registration of bird collisions has been developed by ECN in co-operation with ornithologists that is suitable for large-scale application in both onshore and offshore wind farms. The monitoring system, named WT-Bird®, uses video cameras that are triggered by vibration measurements in the rotor blades. It counts the number of detected collisions and sends detailed alert messages to the operator. Remote access to the recordings makes it possible to assess whether a collision actually took place and to identify the species. A prototype has been tested successfully on an onshore Nordex N80/2.5MW turbine.

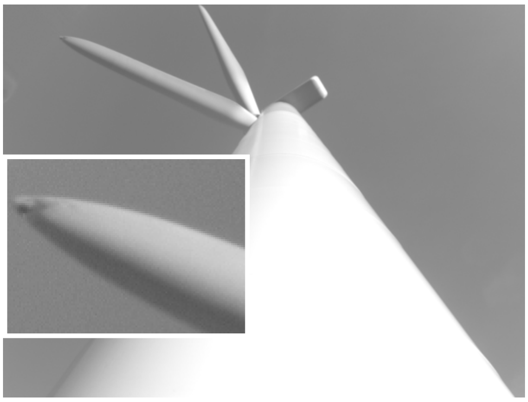
Results of collision detection
Functional tests with bird dummies of only 50 grams and 7 centimetres in diameter, which represent the smallest abundant bird species along the Dutch coastal region, hitting the rotating blades showed that the majority of impacts were detected. Turbine noises under varying operating conditions are suppressed effectively, leading to about 5 to 10 false trigger events a day.

Results video registration
The flight track of the dummies and the collision events were clearly visible on the recordings. The silhouette and flap movements of a passing bird at high altitude can also be distinguished. The image quality at night is still insufficient for species recognition, however rapid improvements are expected in cameras and infrared lighting.



Video registration of passing bird

Benefits
Compared to most other methods this monitoring system can be applied on a large scale and at any location. Continuous monitoring over long time periods will lead to a lower uncertainty in the results. It showed that this system is also suitable for other monitoring tasks, such as the assessment of visual blade damage, which could save time and costs for inspection and repair.

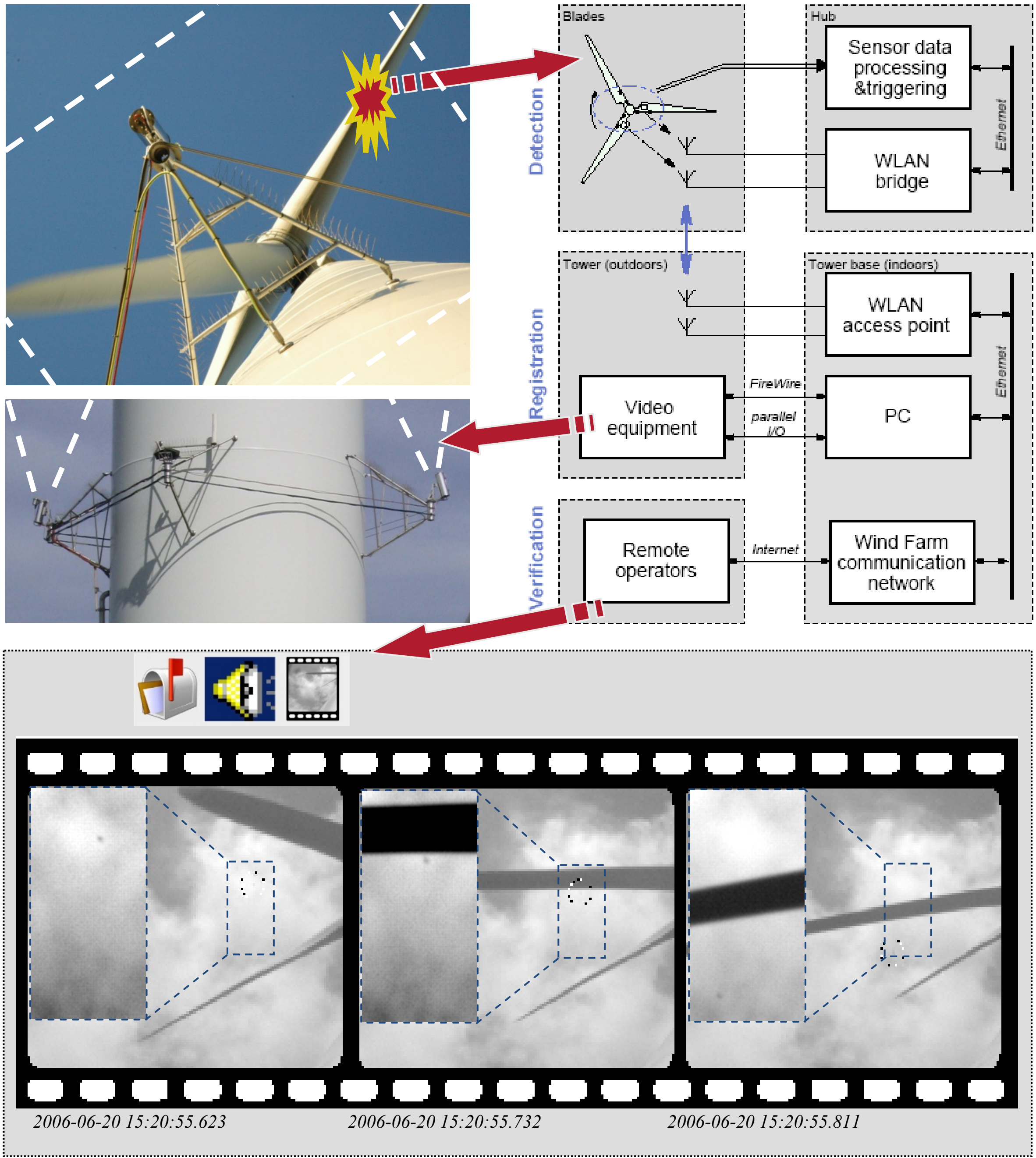


Recording of blade damage from lightning

Verification
To make large-scale application possible it is essential to verify the measurement results from the WT-Bird system once by means of long-term ornithological field searches.

Application

For the application of the WT-Bird system ECN is able to install and maintain the system. ECN will perform the first quality check of the data and the delivery of the data for further analysis.



Schematic overview of WT-Bird operation (upper part) and recorded video image sequence of detected dummy collisions on Nordex N80 .(lower part) Inserts in the video images show the dummy in close-up.

Appendix B Recorded images

B.1 Collisions and other triggered events

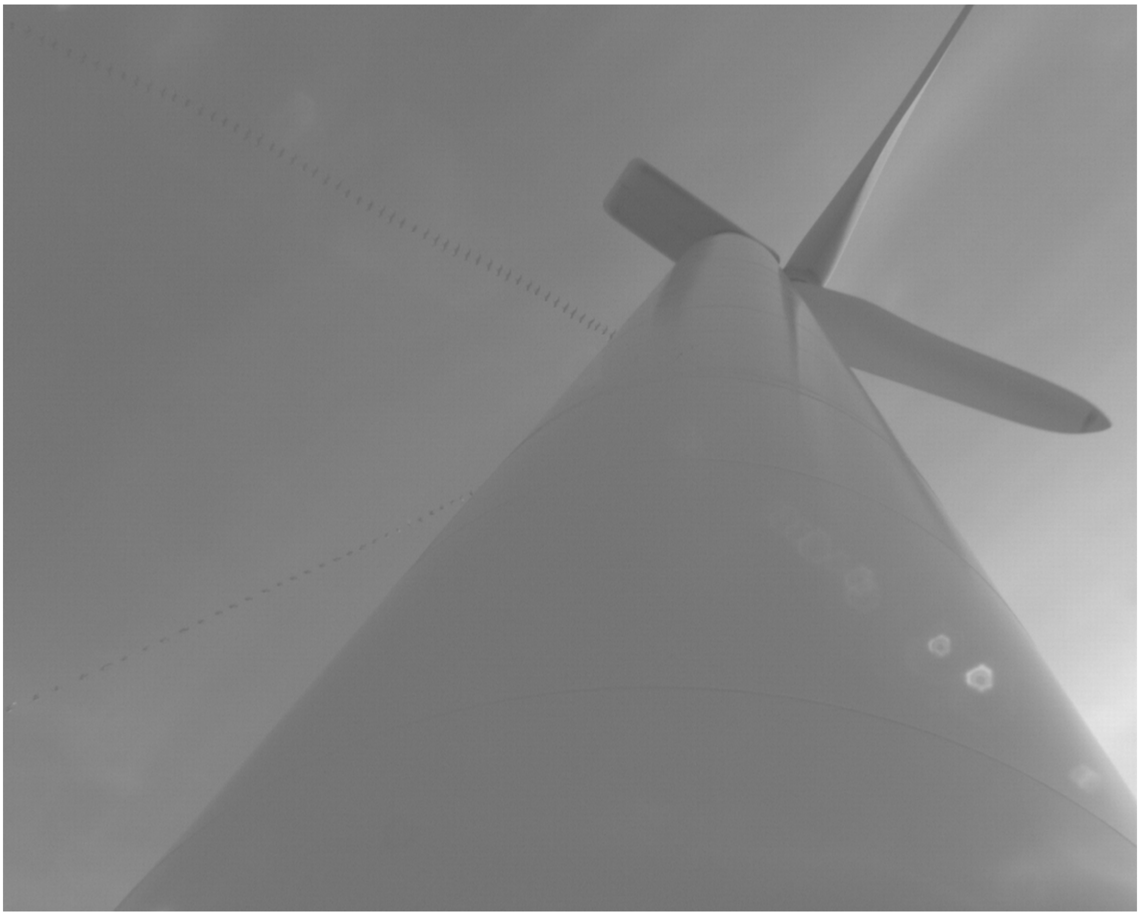


Figure 1: Bird collision on 2008-04-25, composite image of video registrations

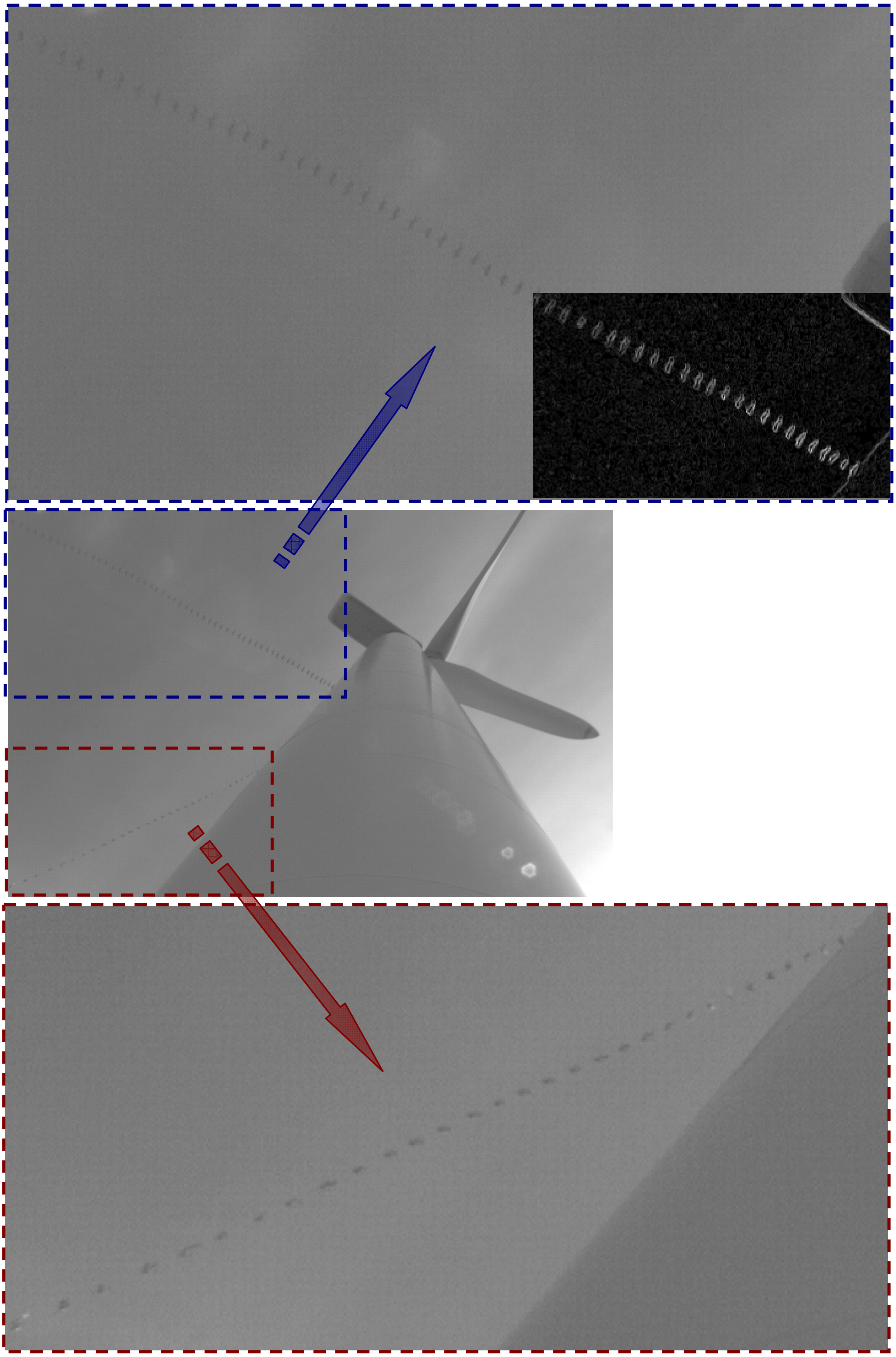


Figure 2: Bird collision on 2008-04-25, details and example of edge detection

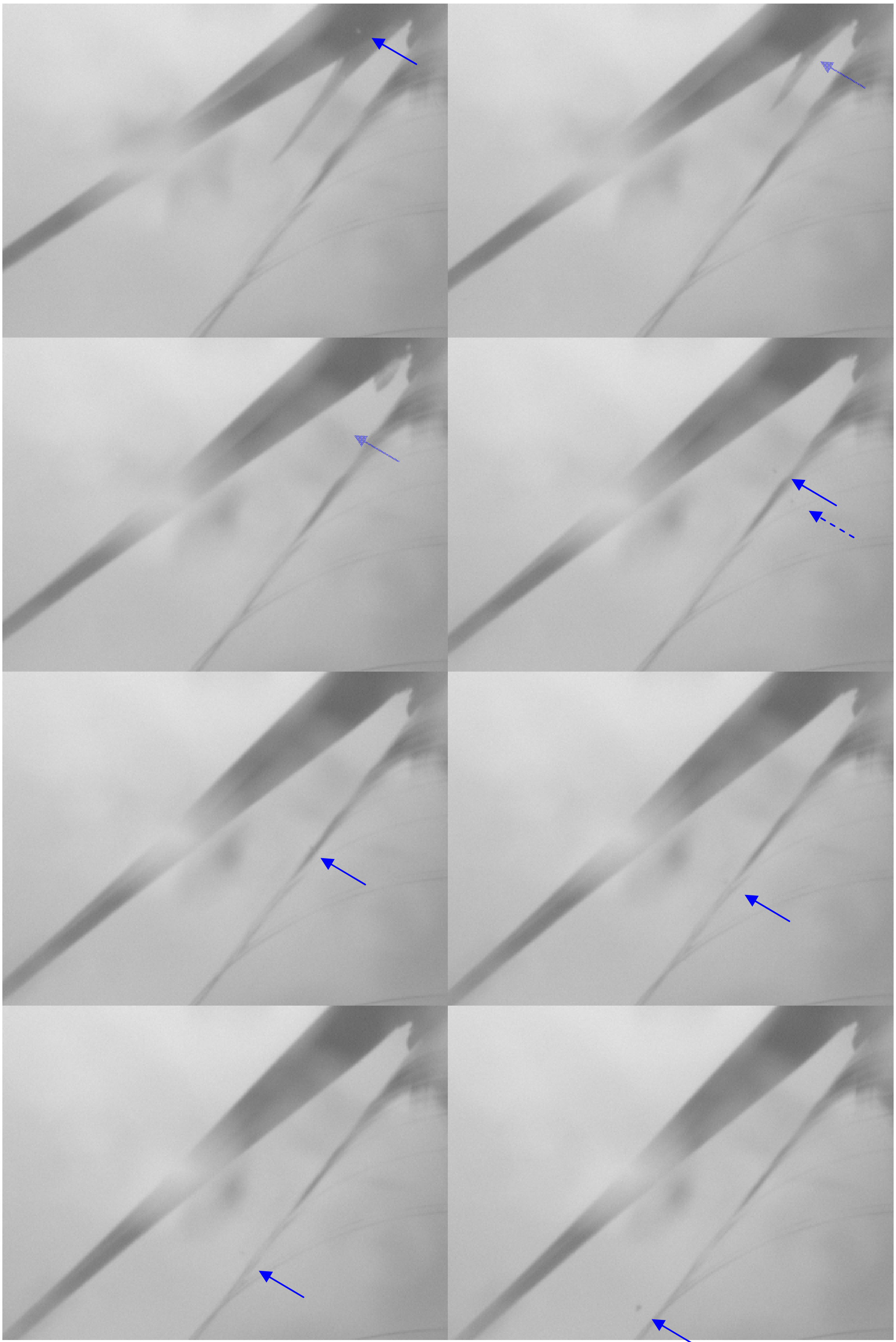
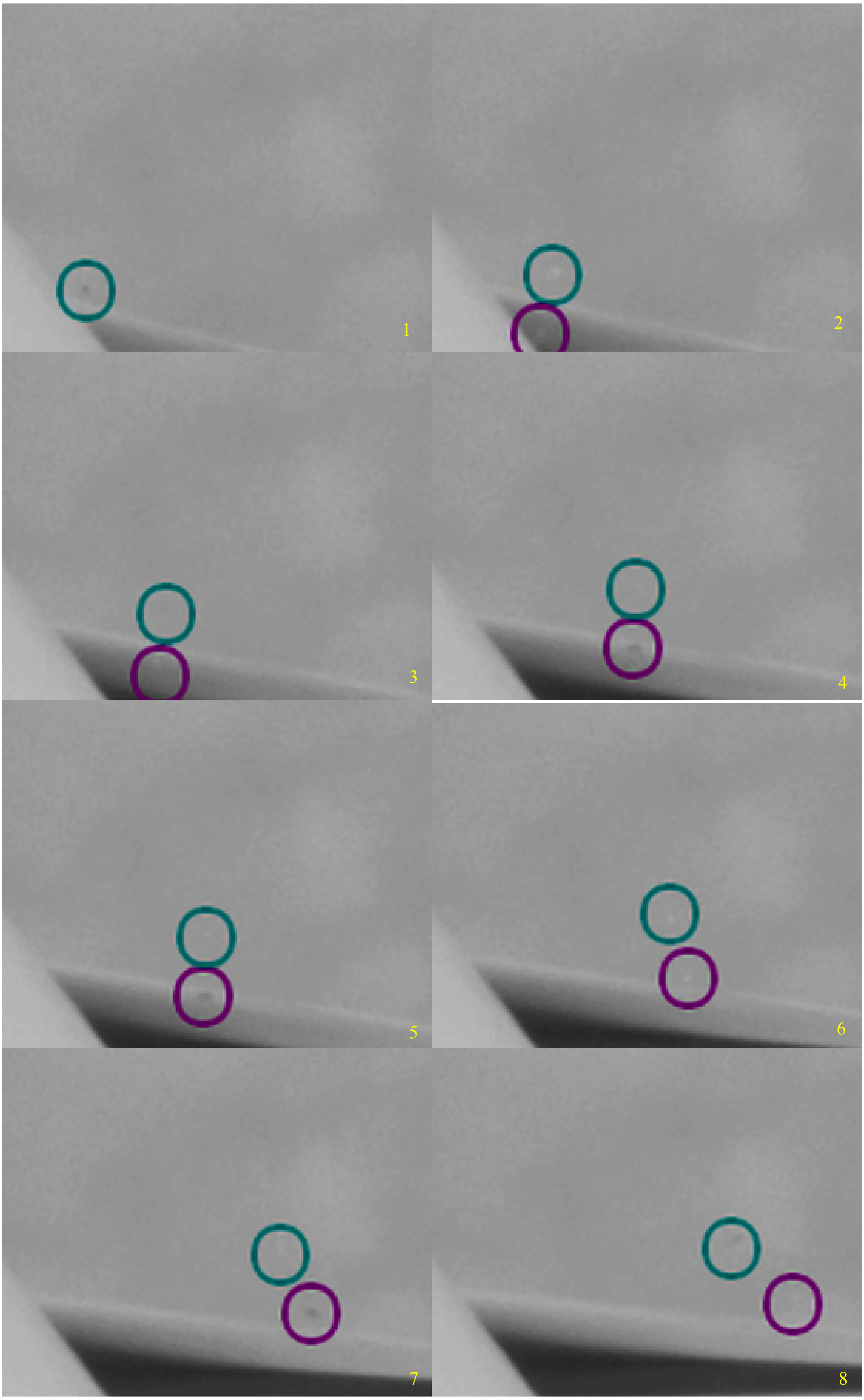


Figure 3: Bird collision on 2007-02-07, showing some sequential video registrations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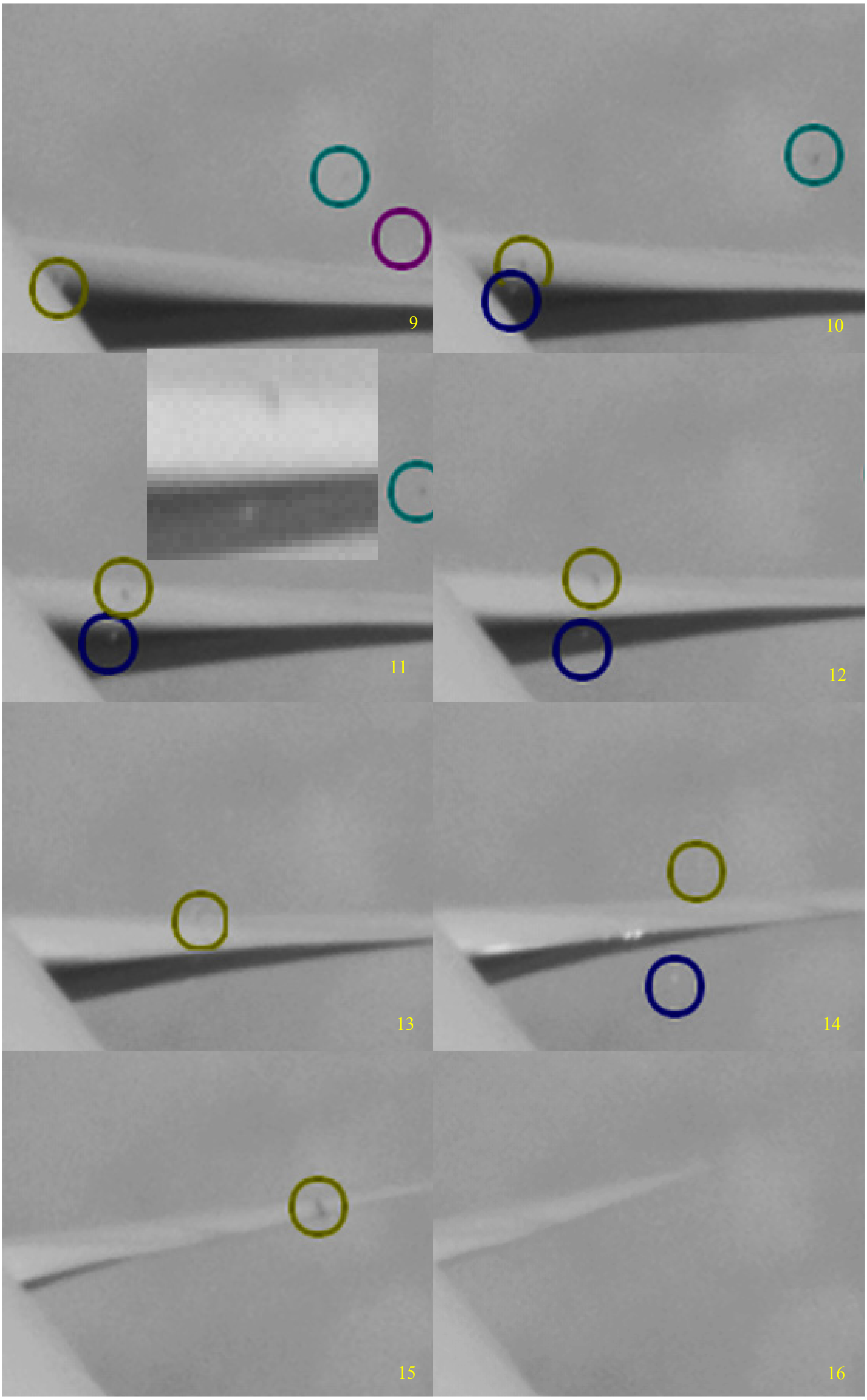

Figure 4: Ice falling off on 2007-03-19, 11:08, cropped images with individual pieces marked

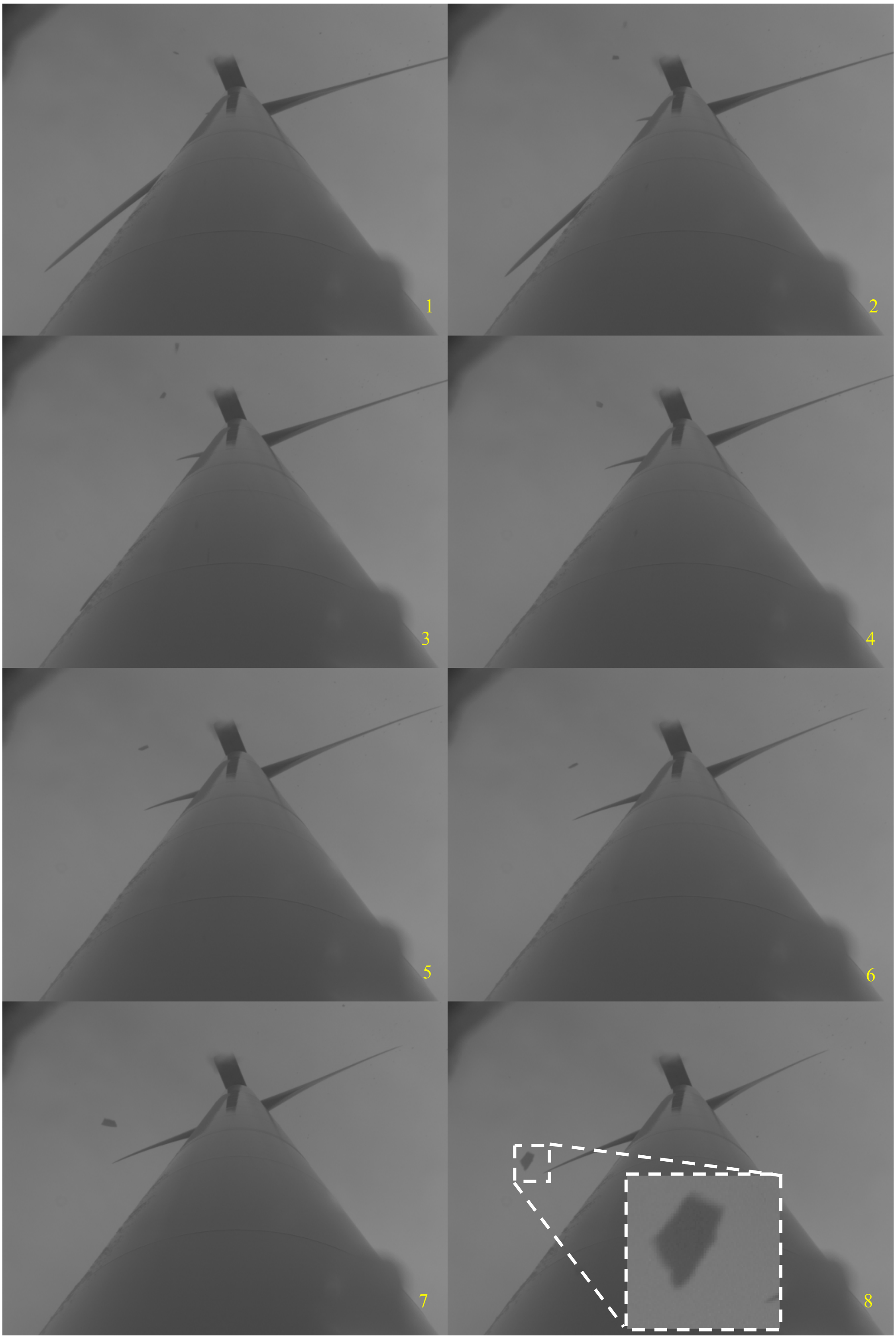

Figure 5: Ice falling of from blades on 2007-03-19, showing some sequential video registrations

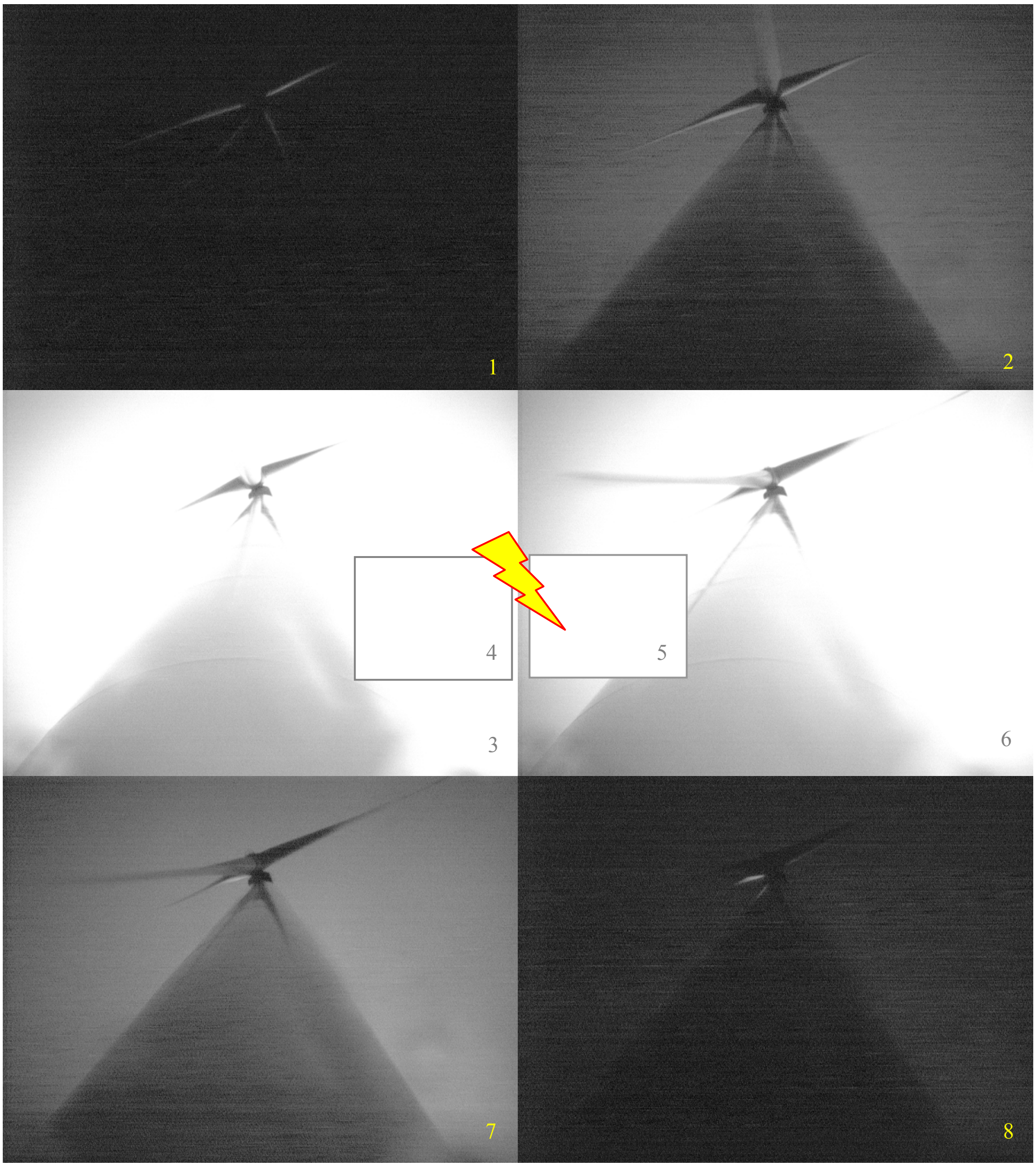

Figure 6: Lightning strike nearby on 2007-03-21, showing some sequential video registrations

B.2 Camera tests

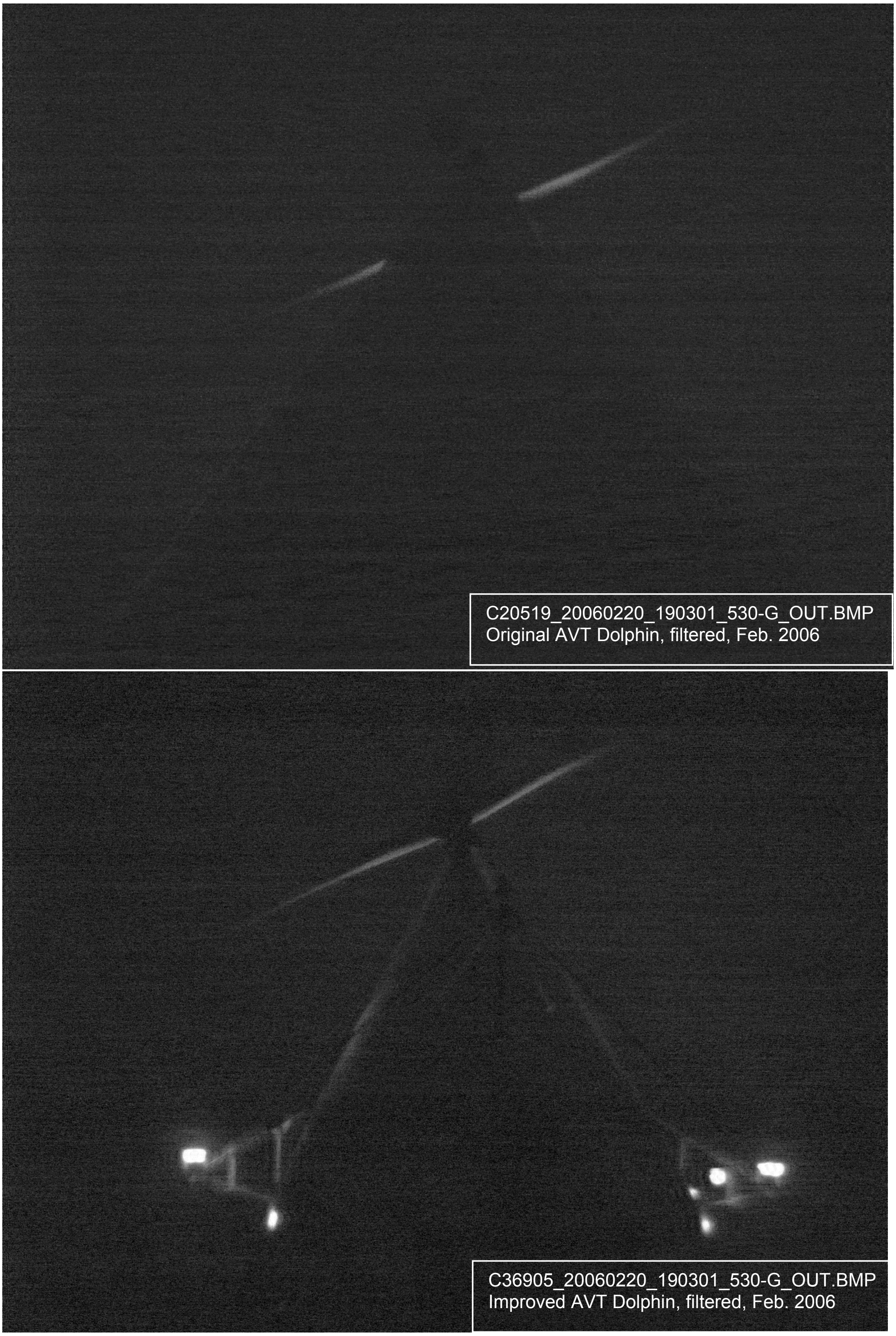

Figure 7: Camera registrations from outdoor test on 2006-02-20

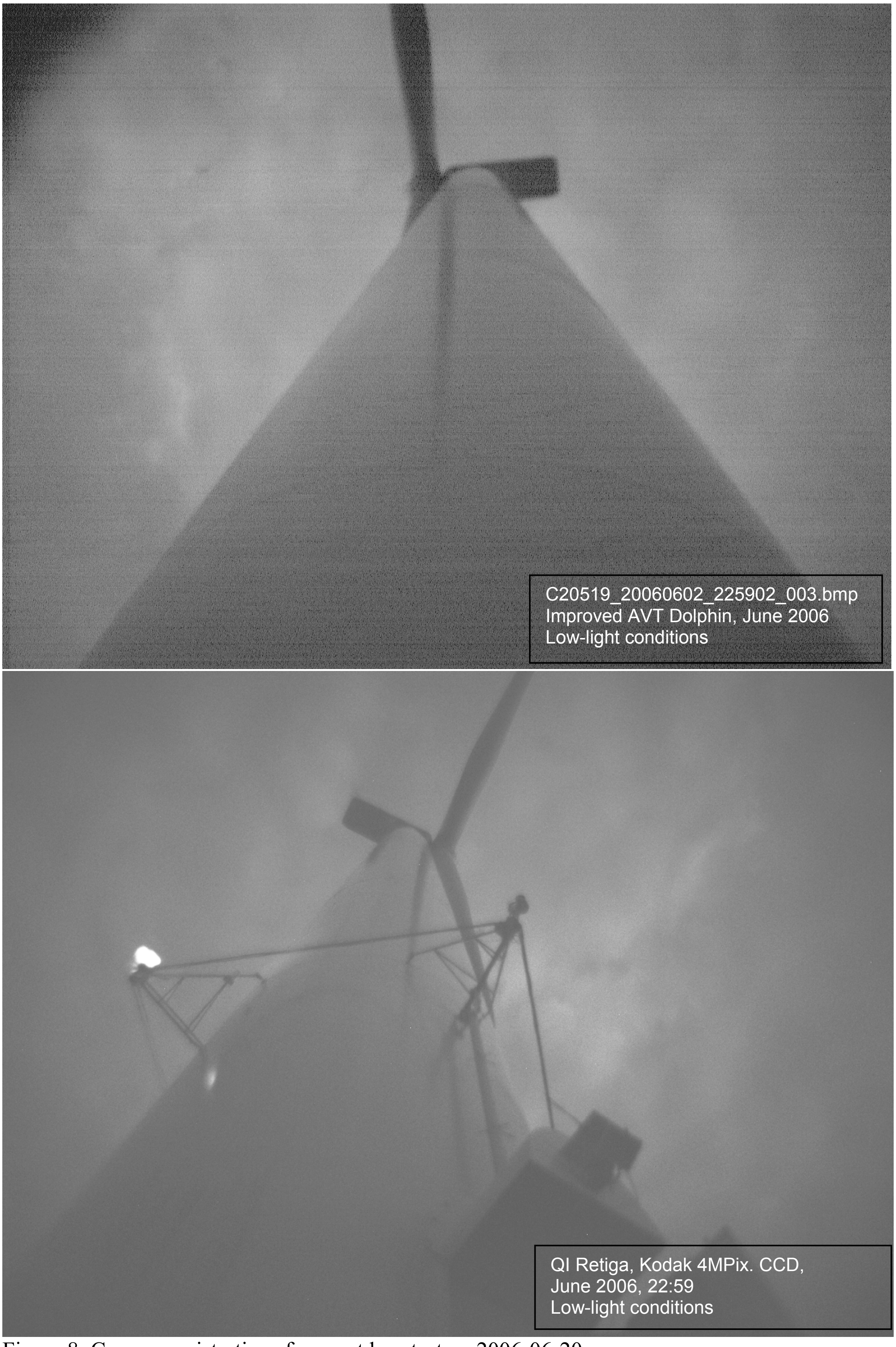

Figure 8: Camera registrations from outdoor test on 2006-06-20

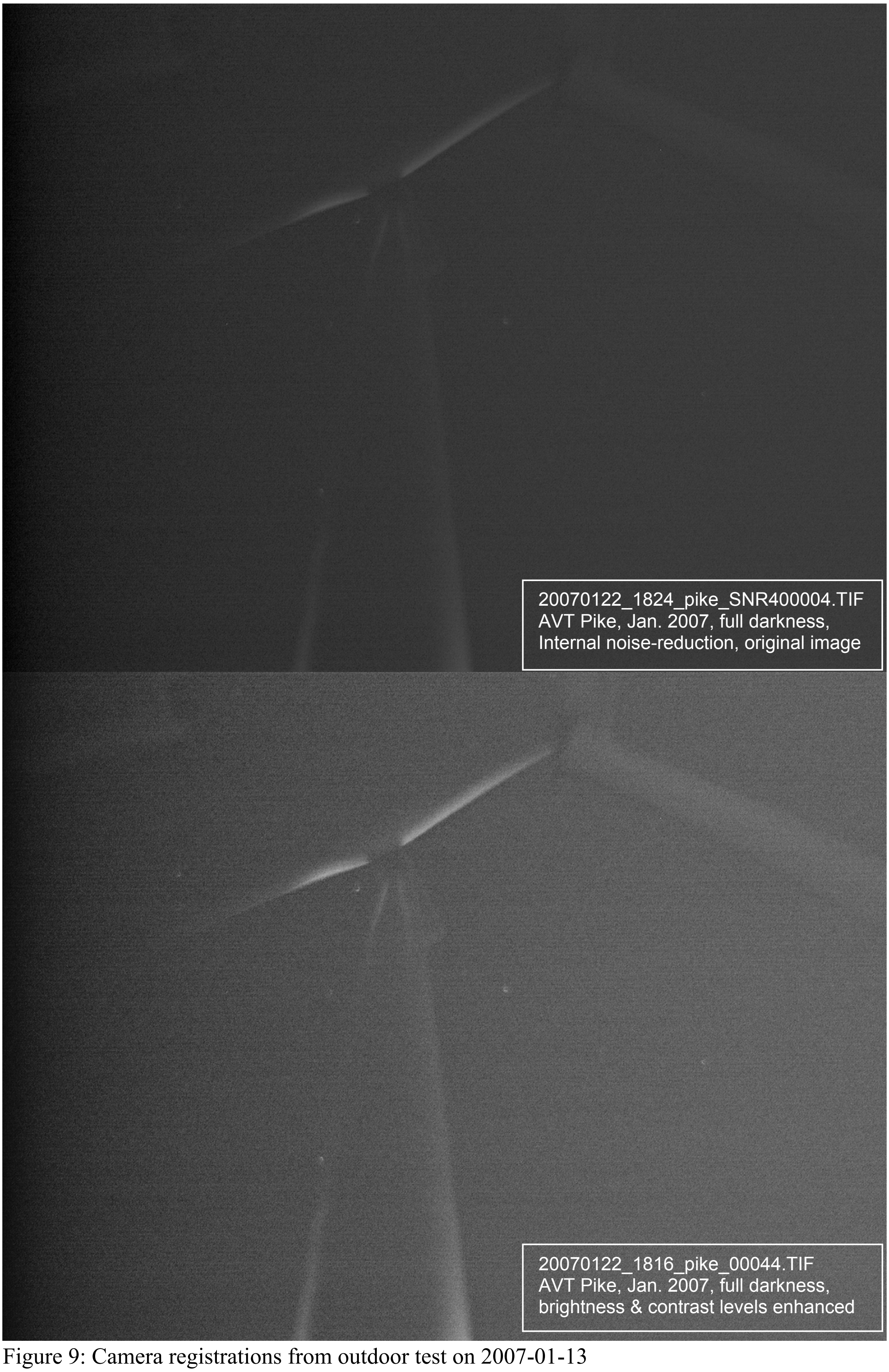

Figure 9: Camera registrations from outdoor test on 2007-01-13

Appendix C Publications and presentations

In the We@Sea Research line 2 meeting the project progress has been discussed on a regular basis, as well as the progress of the system development in the SenterNovem project, which was completed in June 2006.

On December 4, 2006 a presentation was held on the project status – the problems with Vestas were already clear by then – and priorities for further development. It was clear that validation of the system with ornithological field searches in parallel should get priority.

At the conference EWEC 2006 a paper and poster were presented on the operation and possible applications of the WT-Bird system.

At the conference Final Results of the Danish monitoring program in 2006 a poster was presented, which was combined with a video presentation and distribution of DVDs and a leaflets.

During a visit to Nordex a presentation was held on the WT-Bird system.

In February 2007 the web page of WT-Bird was updated and now also includes video and sound fragments form the field tests.

At the conference EWEC 2007 a paper was presented orally with the monitoring results with the prototype in the Wieringermeer together with the distribution of DVDs and leaflets.

Appendix D Generic measurement plan

<Date>

Proposal for monitoring of
bird collisions using WT-Bird
in *<name>* wind farm

Technical work description

D.1 Definitions

Customer	*<Customer>*
Manufacturer	*<Manufacturer>*
Force majeur	An exceptional event not attributable to one of either ECN or the customer including an act of war (declared or undeclared), insurrection, rebellion, sabotage or civil disturbance.
HSE	Health, Safety and Environment
Weather conditions (general remark)	The weather conditions for accessing the turbine and carry out work at the turbine are determined by the wind speed, and lightning. If work has to be carried out outside the nacelle, ECN personnel is not allowed to work above 12 m/s wind speed (10 min. average) or gusts above 15 m/s.
Suitable weather conditions	Weather conditions at which the turbine can be accessed or work can be carried out outside the turbine.
Bad weather conditions	Weather conditions at which the turbine cannot be accessed or work cannot be carried out outside the turbine.

D.2 Summary

D.2.1 Introduction

This memo gives a technical description of the bird collision monitoring campaign that is to be performed in the wind farm <*Name*> located in <*Location*>. This wind farm of <*Owner*> of <*number and type(s) of turbines*>. In this monitoring campaign the WT-Bird® system of ECN, c.f. [2, 3] will be applied to detect and register bird collisions.

The number of systems to be installed as well as their configurations and the monitoring period are to be selected by the customer from a number of options which are described in this memo.

D.2.2 Monitoring results

The raw monitoring results are a list of detected events of possible collisions. For each of these events a fragment of the vibration measurements and the video registrations - if video is installed - is stored. The identification of collisions from these fragments should be done manually by the operator as well as the selection of the monitoring data. These selected monitoring results can be handed over for further analysis, e.g. by ornithologists. Another monitoring result is a detailed log file from which the daily availability of the monitoring systems can be determined.

The monitoring results from the WT-Bird system are owned by the customer, while ECN is allowed to use the data for evaluation of the WT-Bird system. Publication of any monitoring results by ECN or the customer should first be approved by both parties.

D.2.3 Work content

To start ECN will prepare the test- and measurement plan, which is to be approved by the customer. This plan includes a preparatory test program to determine whether and how the WT-Bird systems can be installed and applied successfully in the turbines concerned. ECN will carry out these tests and report the results including an assessment of the feasibility. This document will be discussed with the customer to make a decision for continuation and to specify the installation and the commissioning process.

ECN will prepare the instrumentation and offers to carry out the installation, in close cooperation with the customer and/or the manufacturer. The same holds for the service and maintenance during the measurement campaign and the dismantling after the monitoring has ended.

After installation ECN will perform the configuration and the commissioning of the systems, including a functional test with bird dummies. After commissioning the monitoring will start for a predefined period, for instance 12 months. The customer may extend this period with 3-months periods.

During the first month of the monitoring campaign ECN will check the proper operation of the system daily from Monday till Friday remotely. ECN will also perform the first quality check of the data, such as identification and removal of false collision events. In case that a collision is detected ECN will alert the customer within 24 hours by email and otherwise if preferred. The customer may extend this period with 1-month periods.

ECN will provide a one-day training to instruct local personnel to operate the monitoring system and to interpret the results.

During the period that ECN operates the monitoring system ECN will provide monthly reports (in PDF) to the customer with statistics of the system operation and of the number of detected collisions and other events, which includes selected vibration and video fragments of the detected collisions. The vibration data fragments and the video fragments will be made available in a current audio format and image format. The data storage location and media as well as the method of data access during the monitoring campaign are to de determined.

During the full monitoring period ECN will take care of the service and maintenance of the installed systems. The organisation of the work, such as cooperation with local technicians, will be arranged with the customer.

The work will be carried out by the Group Operations and Experiments of ECN Wind Energy. The measurements will be carried out similar to the internal quality procedures for power performance measurements, mechanical load measurements and noise measurements, as documented in [1]. The work will be carried out in the following 9 phases, which are described in detail in section D.4.

Phase 1: Preparation of test- and measurement plan

Phase 2: Preparatory tests

Phase 3: Preparation of instrumentation

Phase 4: Instrumentation of the turbines

Phase 5: Configuration of WT-Bird systems and data communication infrastructure

Phase 6: Preparation of the instrumentation report "as-built"

Phase 7: Measurements (incl. periodical progress reports and delivery of intermediate data)

Phase 8: Final reporting and delivery of final data set

Phase 9: Dismantling

D.3 Conditions precedent

D.3.1 General conditions

- The application of instrumentation is foreseen only once. In case the instrumentation is damaged by the customer's employees or any of its agents or contractors, or instrumented components are replaced by any of them, the costs to repair the instrumentation will be charged to the customer.
- The customer will facilitate access and support for testing, instrumentation and calibration purposes.
- ECN is allowed to visit the turbines after permission of the customer. If the customer has given permission to ECN employees to carry out work in the turbine but interrupts the execution of the work, the related unforeseen costs made by ECN will be charged to the customer. In case the customer needs to interrupt the execution of ECN's work due to bad weather conditions, for safety reasons, or force majeur, this clause does not apply.
- On request of ECN, the customer will provide the relevant and necessary information to design the instrumentation, to perform the tests and measurements as planned and for reporting.
- If the turbine is not available for instrumentation during the monitoring campaign for a significant period of time, the time schedule will be adjusted in consultation with the customer. Any unforeseen costs resulting from long periods of standstill will be charged to the customer.
- ECN will supply data on the detected collisions but is not responsible for providing information on species recognition, collision risks and the like.

D.3.2 Technical conditions

- The customer will provide a DSL Ethernet connection at the tower base or in the nacelle in each turbine in which a monitoring system is to be installed.
- The customer will provide remote access to ECN in order to observe and configure the monitoring systems and to retrieve the monitoring data.
- For the measurements ECN needs a mains power supply at the following locations:
  - Hub: 230V/50Hz. 200W
  - Nacelle: 230V/50Hz. 200W (if the WLAN is located in nacelle)
  - Tower base: 230V/50Hz. 200W (if the WLAN is located in tower base)
230V/50Hz. 1000W (if video system is installed)
- The customer will allow ECN to install and operate a WLAN system in the park with antennas located in the rotor (blades) and in the nacelle or outside at the tower base.
- The customer will provide appropriate measures to prevent any damage by vandalism or theft of the equipment installed outside of the turbine.

D.4 Technical Work Content

In this section a description of work is described for the preparation, installation, measurement and reporting for a monitoring campaign in the <*Name*> wind farm in <*Location*>. For this campaign a selected number of turbines the turbines will be equipped with the WT-Bird® system of ECN, of which a detailed description can be found in Appendix E.

Phase 1: Preparation of test and measurement plan

ECN will prepare the test and measurement plan, in fact a refinement of this technical memo, which has to be confirmed by the customer. This plan will contain at least the following items:

- A detailed description of the sensors and the other equipment that is to be installed.
- The exact spots in the turbine where these sensors and equipment will be installed. For the vibration sensors it is preferred that several locations are identified, in case that the preparatory tests in phase 2 show that other locations are better suitable to pick up impact sounds from collisions.
- Description of the preparatory tests on a single blade in phase 2;
- Design drawings of the instrumentation and cables, including electrical schemes and mechanical interfaces;
- Procedures for the calibration and periodic calibration checks of sensors;
- Detailed planning of the following phases and refined definition of tasks;

Assistance from the customer in this phase is required (see Section D.5). The customer will receive a draft report for comment.

Phase 2: Preparatory tests (applicable for WT types that differ from Nordex N80)

At present the WT-Bird system has not been installed on a <*WT-type*> turbine. As the system configuration depends on the turbine type the following questions have to be sorted out by means of preparatory tests:

1. What are proper mounting locations and mounting techniques in the blades for the vibration sensors and cabling?
2. What are the main characteristics of the impact sounds that are picked up by the vibration sensors?
3. What are the main characteristics of the operational sounds of the turbine that are picked up by the vibration sensors?
4. In case that video registration and IR (infrared) floodlights are to be installed: What is the required field of view of the camera(s) and IR floodlights and what are suitable mounting locations and mounting techniques?

For selecting proper sensor locations (1) and characterizing the impact sounds (2) a number of dummies will be shot against a still-standing rotor blade on the ground with multiple vibration sensors attached to the blade shell at different locations and with different speeds. For this test a single blade should be made available for two consecutive days (one day for instrumentation and one day for testing). Preferably the blade should be bolted at the flange and be unsupported. The dummies are either ordinary tennis balls or tennis balls with filling material to increase the mass or stiffness. The final locations are specified in the test and measurement plan, which is to be approved by the customer. For information: in the current prototype with LM 38.3 blades two sensors are installed in each blade near the leading edge at 4m and 10m from the blade root.

The characterization of operational sounds (3) can only start after the rotor instrumentation of the (first) turbine has been completed. In this test a number the measurements from the vibration sensors are registered during several operational conditions, e.g. normal operation at different wind speeds, starts and stops, etc. These recordings are used to configure the signal processing algorithms and to set trigger levels. Therefore this preparatory test is executed in parallel with phase 5, which is the system configuration.

The location and orientation of cameras and IR lights (4) will be determined by making video registrations at daytime and at night. For practical reasons all equipment will be placed on ground level, so that only an indication of the positioning of the equipment can be obtained. After the instrumentation in phase 3, the orientation of the cameras and lights can still be adjusted.

ECN will carry out these tests and report the results including an assessment of the feasibility. This document will be discussed with the customer to make a decision for continuation and to specify the installation and the commissioning process.

Phase 3: Preparation of the instrumentation

ECN will prepare the instrumentation in their laboratories. This includes among others: purchasing of parts, production of mounting structures and mechanical interfaces, configuration of the measurement platform and the PCs, cables and connectors, testing and calibration of measurement chains, filling out check lists and quality documents.

Phase 4: Instrumentation of turbines

The installation of the hardware (phase 4) can be split into three main activities:

1. Installation of vibration monitoring system in the rotor

The instrumentation of the rotor equipment consists of installation of vibration sensors in the blades and cabling to the hub as specified in the test- and measurement plan.
The measurement platform and WLAN Bridge in the hub are enclosed in a steel cabinet with a single mains connection and surge-protected cable inlets. The WLAN antenna(s) will either be installed in the front of the nose cone or in two blades.
At the non-rotating side of the WLAN link two antennas are to be installed at opposite sides of the tower on the same mounting structures as the other outdoor equipment for video registration. In case that no video registration is installed these WLAN antennas could also be mounted at another location near an Ethernet connection, e.g. in front of the nacelle.

2. Installation of the video registration system on the tower

The mounting of video equipment will be prepared as far as possible in the laboratory. The equipment will either be attached to the tower at a height of a few meters above the door or be placed next to the tower, e.g. fixed to the ground.
All electrical connections to the antennas and the other outdoor equipment will be protected by means of surge arrestors, which will be installed close to the cable inlet. Also appropriate mechanical protection, such as pipes and inlets will be installed.

3. Installation of data communication hardware

For a monitoring system without video registration, the vibration data (of several systems) can be stored directly on a central PC data in the farm. When also video registration is to be installed, for each system a local PC will be installed that will serve as storage location for the both video and vibration data.
The installed PC(s) should be configured to allow remote access to the operator and ECN.

ECN offers to carry out the installation, but the customer or a third party may also carry out (part of) this work as specified in the agreed measurement plan of phase 1.

Phase 5: Configuration of WT-Bird systems and data communication infrastructure

ECN will configure the WT-Bird systems in such a way that:

- the customer receives the e-mail alerts of detected collisions;
- the measured channels (see Section Appendix E) are defined uniquely;
- the measured data and data logging of the WT-Bird systems can be downloaded.

Phase 6: Preparation of the instrumentation report

The work carried out in the phases 2 through 4 will be reported in the instrumentation report. This report will include:

- the "as-built" instrumentation, including sensors and their locations;
- calibration data of vibration monitoring system;
- functional description of WT-Bird system with reference to software version;
- configuration settings (trigger levels);
- results of the functional tests;

Phase 7: Measurements

- During the first period in which ECN will operate the WT-Bird systems, ECN will:
    - daily evaluate the system operation and analyse the detected collisions. All false trigger events will be rejected, meaning that the vibration monitoring data is moved to a separate location "false triggers" and the video data is deleted;
    - alert the customer as soon as a collision has been identified as a real bird collision, but at least within 24 hours, or on the next Monday, so that ornithologists can start searching for the bird casualty;
    - provide the vibration data and video recordings (in current data formats) of the detected collisions on monthly basis, after quality checks, e.g. removal of false trigger events;
    - provide a monthly progress report in PDF-format with logging data and daily statistics of the availability of the monitoring system, the number of detected collisions and the number of identified collisions with references to the stored data;
    - provide a one day training to local operators.
- During the measurement period of one year, with an option for extension per 3 months, ECN will provide service and maintenance to the monitoring systems. In case of malfunctioning of the monitoring systems, we normally will respond within 24 hours after it has been detected or reported by the operator. In case of a failure during the weekend we will respond the next Monday. However depending on the reason of malfunctioning, weather conditions and accessibility of the turbine it cannot be guaranteed that the problem is solved immediately. In this case the customer is informed and repair activities are scheduled in mutual agreement.

Phase 8: Final reporting and delivery of final data set

At the end of the project the customer receives a final report in PDF-format containing daily and monthly statistics of the availability of the monitoring system, the number of detected collisions and the number of identified collisions with references to the stored data.

At the end of the project the final data (all vibration monitoring and video data of the identified collisions and all statistical data) will be delivered on a portable hard disk (to be provided by the customer).

Furthermore, the report will contain the deviation with respect to the instrumentation report of re-calibrations, and relevant details about the data evaluation, processing and storage.

Phase 9: Dismantling

After the measurement campaign the installed hardware will be removed from the turbine. It will be agreed upon with the customer to what extent the hardware needs to be removed from the turbine and if some sensors can be left behind in the turbine, e.g. vibration sensors. ECN offers to carry out this, but the customer or a third party may also carry out (part of) the work.

D.5 Assistance, support, and information from the customer

To carry out the measurement campaign, assistance and support from the customer is required in the different project phases and information is required.

Phase 1: Preparation of test and measurement plan

- A meeting with the customer is necessary to discuss the entire approach of the campaign, to refine the planning, and to settle all items that could not be agreed upon when the offer was made.
- The customer should provide relevant design information of the turbine, such as design drawings of the tower, the blades and the hub, needed to determine preferred locations and mounting provisions for sensors, antennas, measurement equipment and cabling.
- The customer should provide information of the wind farm terrain that is relevant for access and for installation of outdoor equipment.
- The customer should arrange a visit to the turbine for ECN to inspect and discuss the possible locations and available provisions as well as safety matters.
- During the preparation of the measurement plan it is likely that issues will show up which have not been foreseen when making the offer. The customer should then provide additional information on request.
- The customer should approve the draft test and measurement plan before the actual work starts. The customer should give its comments preferably within two weeks after the draft has been received from ECN.

Phase 2: Preparatory tests

- The customer should arrange that ECN could instrument a single rotor blade and perform impact tests with dummies.
- For pressurizing the dummy launcher the customer should provide a Nitrogen cylinder with regulator, flow meter and purge system on site. Further specifications are to be discussed with ECN.
- The customer should provide access to the turbine to make video registrations.
- After instrumentation of the rotor equipment in the first turbine the customer should give ECN one month before the start of the monitoring campaign to characterize the turbine operational sounds and to configure the signal-processing algorithms.

Phase 3: Preparation of instrumentation

- Any assistance and support from the customer in this phase will be answering questions from ECN on instrumentation details.

Phase 4: Instrumentation of turbine

- The customer will assure that ECN personnel can work safely in and around the turbine.
- The customer should provide access to the turbine, in particular to the blades, the hub and the tower base, because these are locations where the equipment will be installed. The customer should give permission to install vibration sensors in the blades, connect these to a data-acquisition system in the hub and a WLAN system with antennas in the hub. Further equipment to be installed is a PC with I/O, power supplies and a WLAN system in the tower base, connected to video equipment and WLAN antennas outdoors. For the existing prototype this equipment is mounted at several meters above the door entrance on four tripods that are fixed to the tower on friction, but alternative mounting locations can be specified in the test and measurement plan.
- The customer will assist in performing tests if necessary.

Phase 5: Configuration of data acquisition system and database

- Any assistance and support from the customer in this phase will be answering questions from ECN.

Phase 6: Preparation of the instrumentation report

- Any assistance and support from the customer in this phase will be answering questions from ECN.
- The customer should comment the draft instrumentation report, preferably within two weeks after the draft for comment has been received from ECN.

Phase7: Measurements

- The customer should inform ECN on any maintenance work, loss of mains power or network connection in order to enable ECN to analyse the operation of the monitoring equipment and to analyse the incoming trigger events.

Phase 8: Final reporting and delivery of final data set

- Any assistance and support from the customer in this phase will be answering questions from ECN.
- The customer should comment the draft final report, preferably within two weeks after the draft for comment has been received from ECN.

Phase 9: Dismantling

- No assistance from the customer's personnel is foreseen in this phase.

D.6 Planning and time schedule

Dependent upon measurement campaign.

D.7 HSE

- The labour safety conditions and the electrical safety comply with the standards valid in the Netherlands.
- ECN will carry out the work in accordance with the detailed procedures for ECN personnel to work in wind turbines safely. They are described in [1] and can be provided on request.
- The customer will make sure that ECN personnel can work safely in and around the turbines.

D.8 Deliverables

Phase 1: Preparation of measurement plan

1. Test and Measurement plan as PDF-file.

Phase 2: Preparatory tests

2. Test results

Phase 6: Preparation of the instrumentation report

3. Instrumentation report.

Phase 7: Measurements

4. E-mail alerts on detected collisions and reporting of identified collisions within 24h during the first month of the measurement campaign
5. Monthly progress reports as PDF files with data of identified collisions during the first month of the campaign as well as daily statistics of the system performance
6. One-day instruction of local personnel for operating the monitoring system
7. Service and maintenance of the installed monitoring systems; organization to be agreed upon with the customer

Phase 8: Final reporting and delivery of data

8. Final report.
9. Final set of selected video registrations and vibration measurements on a portable hard disk or DVDs. The customer should provide this hard disk.

Phase 9: Dismantling

10. All measurement equipment removed.

D.9 Warranties

Warranties with respect to malfunctioning or unavailability of the WT-Bird system are customer-specific.

D.10 Cost estimates

A detailed cost estimate will be included after the following information is made available:

- The number of monitoring systems that is foreseen.
- The configuration of the systems, e.g. with or without video registration.
- The planned start date and duration of the monitoring
- Any specific needs, e.g. with respect to reporting.

In this cost estimate ECN will specify development costs and application-related costs separately, in case the WT-Bird system should be made suitable for a new type of turbine. This is because the customer will only be charged for a fraction of the development costs.

D.11 References

[1] ECN Management System: *Gestandaardiseerde metingen aan windturbines*, 2003

[2] ECN-E-06-027: *Bird collision monitoring system for multi-megawatt wind turbines WT-Bird, Prototype development and testing,* Oct. 2006

[3] ECN-E-06-028: *Bird collision monitoring system for multi-megawatt wind turbines WT-Bird, Summary of prototype development and testing,* Oct. 2006

Appendix E Description of WT-Bird system

E.1 Triggering

The WT-Bird system consists of acceleration sensors in the blades (two in each blade) that pick up the impact signal from a bird collision. The sensors in the blades are connected to a measurement platform in the rotor with real-time signal processing capabilities. A dedicated signal-processing algorithm recognizes the impact signal among other operational noises from the turbine and other external sources, cf. figure 1.

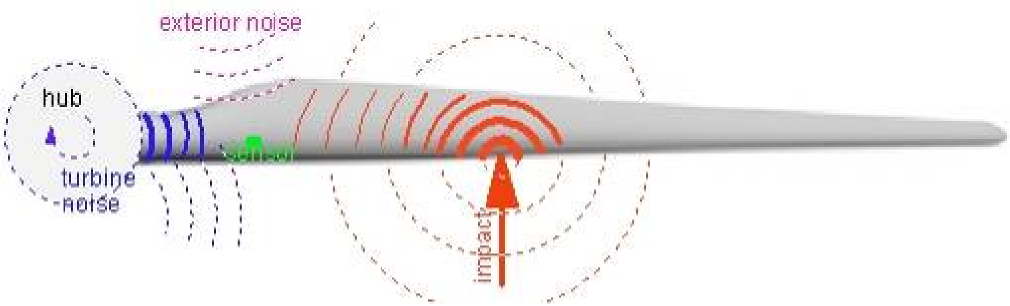

Figure 1: Simplified scheme of rotor blade with a single acceleration sensor that picks up vibrations from several sources.

When a collision is detected a trigger is released with a number of predefined actions. First the platform stores the vibration monitoring around the trigger event data on a local flash disk, sends an email alert message to a list of addressees and sends a trigger signal to the PC located in the tower base. Then this PC transfers the data from the flash disc and also to stores the selected video registrations in which the collision is visible. The pre-trigger time is >40 sec. and the post-trigger time >20 sec. and both are user-defined.

The data communication over Ethernet can be implemented by means of a Wireless LAN link between the rotor and the tower base. Suitable antenna types and locations are dipole antenna in the nose cone, which is preferred, or two wide-beam strip antennas, in the root of two different blades. At the non-rotating side two directional antennas are mounted at two opposite sides of the tower near the cameras. The scheme in Figure 2 gives an overview of the equipment and the data communication structure of the WT-Bird prototype installed on the Nordex N80 turbine in the ECN Wind turbine Test park Wieringermeer (EWTW).

E.2 Video registration

The PC in the tower base controls all camera functions, such as image acquisition and exposure control. For exposure control the PC continuously determines the image brightness and contrast on a user-specified grid of pixels and controls the camera gain, shutter time and gamma setting as well as the lens iris. The acquired video images are stored at a temporary location on hard disk for a certain user-defined time, e.g. 10 minutes. After a collision event the selected data is moved to a permanent location. The PC regularly performs time synchronisation with the measurement platform in the rotor.

The cameras are installed in stainless steel camera housings with temperature control against condensation or freezing and a flat lens cover to prevent for the accumulation of water, snow and dirt. Both housings are equipped with a washer wiper unit, which is controlled by the tower base PC in combination with precipitation sensors near the cameras.

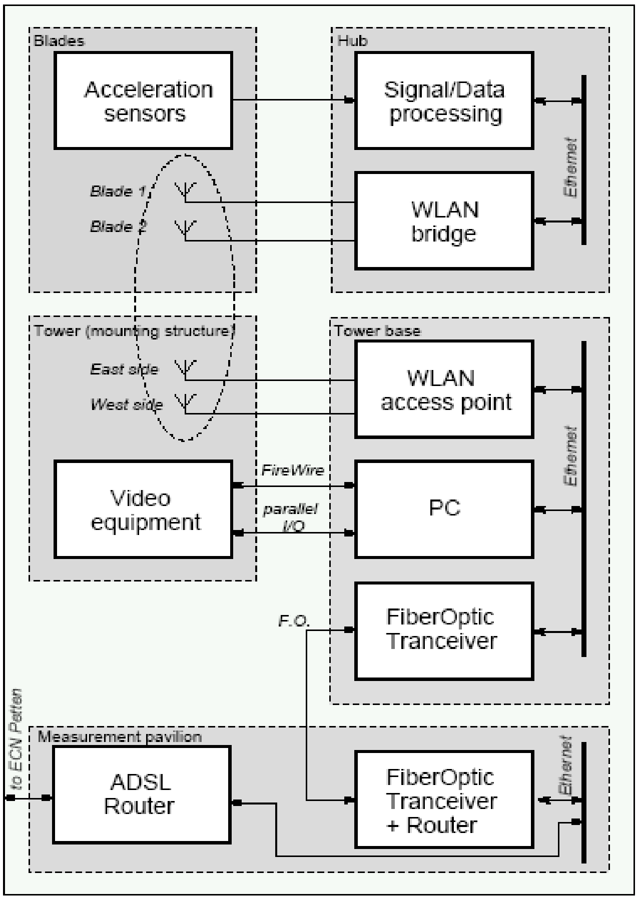

Figure 2: Communication infrastructure for WT-Bird on the N80 at ECN's test site EWTW

E.3 Equipment mounting

All equipment outdoors is mounted on four identical tripods mounted at about 1 meter from the tower wall. The user can determine the height at which the equipment is mounted, as the tripods are applicable for a wide range of tower diameters. However it is obvious that the system should not be accessible for vandals but should also not complicate the installation.

The total weight of the mounting structure with equipment is about 100 kg. Two steel cables, each forming a square and do not touch the tower, pull the tripods against the tower wall, so that the structure is fixed on friction. The tripods rest on pads of synthetic material that have a flexible joint. All separate parts and the steel wires are earthed. During installation the individual tripods with equipment are fixed to the tower with magnets, which for a concrete tower could be carried out with a (steel) belt instead. After the two steel cables are led through quarter circle steel tubes at the outside of each tripod and tied together, the magnets are removed. The electrical wiring is lead along the steel cables and through a vertical pipe to the inlet, which is the ventilation shaft in case of the Nordex N80 turbine.

To enhance the contrast of the acquired images at night and during other periods with poor visibility, several infrared lights are installed. The current set up has four infrared LED lights mounted at the same height as the cameras and three on top of the nacelle. The lights are 48W, each and have a beam width of 30°. The IR lights have a wavelength of 880 nm, which is invisible for both birds and humans.

Figures 3a, 3b and 3c show a camera and infrared lights mounted on a Nordex N80 turbine at the ECN test site. Figure 4 shows a detail of the installation of the mounting structure.

Figure 3a, b: Outdoor equipment of the WT-Bird prototype on tower of Nordex N80 turbine at EWTW

Figure 3c: Outdoor equipment of the WT-Bird prototype on nacelle of Nordex N80 turbine at EWTW

Figure 4: Installation of mounting structure with cameras, IR lamps and WLAN antennas

E.4 List of measurements

For each detected collision event a number of measurement signals are stored:

- Vibration in single direction, perpendicular to the sensor mounting plane at each sensor location in the blade (two sensors per blade at different radial positions)
- Vibration in single direction, perpendicular to the sensor mounting plane at each sensor location in the hub (optional)
- Acoustic sound pressure (not calibrated) from boundary microphone (optional)
- A selection of online-processed monitoring signals at 4 Hz., such as the signal levels (user-defined).
- Selected video images of the installed cameras at 10 frames per second, grouped in 1-minute files, which can be extracted offline into separate files with single images.

Additionally the status logs of the monitoring system are stored.

Remarks:

- The maximum number of vibration measurements per measurement platform is eight. The measurement period, which is user-selectable, is set to 20 seconds with 7 seconds pre-trigger time. The sample frequency in set to 5 kHz.
- The number of cameras can be chosen as either one or two.