April 2004 ECN-C--04-046
November 2003 ECN-CX--03-091

WT-Bird
A Low Cost Solution for Detecting Bird Collisions

J.P. Verhoef
P.J. Eecen
R.J. Nijdam
H. Korterink
H.H. Scholtens

Acknowledgement/Preface

The work was partly financed by NOVEM, and partly by ECN Wind Energy.
The authors want to thank the Dutch Utility NUON, the Helderse Windmolen Coöperatie "De Eendragt" u.a and ENECO Energy for hosting our equipment.

ECN project number : 7.4172
Novem contract number: 2020-01-13-10-005

DISTRIBUTION LIST

Novem	1 - 4
A.B.M. Hoff	5
C.A.M. van der Klein	6
W.C. Sinke	7
H.J.M. Beurskens	8
J.P. Verhoef	9
P.J. Eecen	10
R.J. Nijdam	11
H. Korterink	12
B.H. Hendriks	13
L.W.M.M. Rademakers	14
H. Braam	15
H.H. Scholtens	16
Archive ECN wind energy	17 - 27
Central archive ECN	28

CONTENTS

SUMMARY

The large-scale implementation of wind energy is hampered to a large extent by the unknown effects that wind turbines may have on the environment. The collision of birds with turbines and the distortion of the migration routes are in that respect points of great concern. The project "*WT-Bird , A low cost solution for detecting bird collision*" focused on developing a reliable and cheaper method for counting bird collisions in order to obtain more insight in the actual size of the problem, especially in offshore applications for which no alternative detection method is available.

The report describes the work that has been performed to meet the objective "developing and demonstrating a system that determines a bird collision against a wind turbine and with which it is possible to determine the bird species". The system had to meet among others the following specifications:

- the system should be low cost in order to be competitive with manual counting methods;
- analysis of recorded data by e.g. ornithologist should not be labour intensive, meaning that only actual collisions should be recorded and no false data should be stored;
- the system should be able to operate under all weather and visibility conditions;
- the system should operate in offshore wind farms for long periods in a reliable manner and data should be accessible remotely.

The assembly of the prototypes has been carried out in this project successfully. They behaved robust and reliable during the field tests and only minor problems have been identified. Two major problems have not been solved completely in this project.

1. Triggering
   Birds can collide against rotors and towers in many different ways. The tests that have been performed with shooting tennis balls against the flat side of rotor blades and throwing sand bags against the tower did not cover the entire range of possible bird impacts. Secondly, the variety of possible microphone configurations and background noises for especially larger turbines is bigger than originally expected. The determination of a good algorithm for triggering should be further investigated. Within the constraints of the project, more detailed investigations were not feasible.

2. Image recording and recognition of bird species
   Already at an early stage in the project it was decided to use the Mobotix camera a.o. because it had a normal lens and a low-light lens, it could be accessed with commonly used web browser technology, and especially because it was cheap. During the field tests, the shortcomings of the camera became clear. The view during night-time was insufficiently clear for recognition of species. Additional light sources were necessary and the exposure time is too long, leading to too low sample frequencies. A large part of the project has been spent on improving the visibility during night-time but without being completely successful.

To solve these problems, further R&D work is recommended. More tests with dummies against larger turbines should be performed and the tests with cameras should be continued. Moreover, much more long-term field tests should be performed in close collaboration with ornithologists.

1. INTRODUCTION

1.1 Background

The large-scale implementation of wind energy is hampered to a large extent by the unknown effects that wind turbines may have on the environment [6,9]. The collision of birds with turbines and the distortion of the migration routes are in that respect points of great concern. In environmental impact studies, estimates are made of the number of birds killed trough collisions or from exhaustion [1,3,4,7,8]. After the wind farm has been taken in operation, again investigations have to be carried out to verify if the estimates were right. To overcome especially the aspects that deal with colliding birds, ECN has initiated the project "*WT-Bird , A low cost solution for detecting bird collisions*".

The most commonly used techniques for counting bird collisions in an onshore wind farm are: manual search for corpses in the vicinity of the wind turbines, or by using radar. Both methods have in common that they are labour intensive, and thus expensive and time consuming. Usually the investigations end up with very few figures and large uncertainties. Offshore, these methods are hardly feasible. Corpses cannot be searched for, and radar still remains expensive. Moreover, investigations with radar in fact aim at distortion of migration routes more than on bird collisions.

The project "*WT-Bird , A low cost solution for detecting bird collision"* focused on developing a reliable and cheaper method for counting bird collisions in order to obtain more insight in the actual size of the problem, especially in offshore applications for which no alternative is available. Finally, this should lead to the situation that the deciding on placing wind turbines or not, can be taken on a more rational basis underpinned with actual facts and figures.

1.2 Objectives and Scope of Work

The objective of the project has been formulated at the time as "developing and demonstrating a system that determines a bird collision against a wind turbine and with which it is possible to determine the bird species". The system had to meet among others the following specifications:

- the system should be low cost in order to be competitive with manual counting methods;
- analysis of recorded data by e.g. ornithologist should not be labour intensive, meaning that only actual collisions should be recorded and no false data should be stored;
- the system should be able to operate under all weather and visibility conditions;
- the system should operate in offshore wind farms for long periods in a reliable manner and data should be accessible remotely.

During the definition phase of the project it was already recognised the above mentioned objective and specifications were very ambitious. To limit the scope of work some boundary conditions were defined already:

- microphones will be used for determining the impact and triggering sound and image recordings;
- low cost video cameras or web cams will be used for recognition of bird species;

1.3 Work Plan

To meet the above-mentioned objective, a work plan consisting of 3 major tasks has been defined.

Task 1: Development of measurement method
In this task, the emphasis was put on demonstrating the proof of principle. Tests with tennis balls and other bird dummies have been carried out at two types of turbines. The results are described in Chapter 2.

Task 2: Development of measurement system
Based on the positive results of Task 1, it has been decided to develop the actual measurement system with which bird collisions can be recorded automatically. First, an extensive set of ambitious specifications was defined (Chapter 3). During the development of the system, two major problems had to be solved, namely

- selecting and improving a camera to make sure that it can be used for recognition of species under all weather and visibility conditions (Chapter4) and,
- selecting a suitable microphone configuration and developing an algorithm for sound analysis with which bird impacts can be discriminated from operational sounds of the turbine, e.g. slamming doors, yawing, pitching, etc. (Chapter 5).

During the execution of Task 2, it appeared that the problems related to detecting impacts and recognition of species were much more complex than assumed during the definition of the project. The current prototype does not meet all specifications defined in Chapter 3.

Task 3: Detection of species
Task 3 was defined to find out if different types of species indeed could be recognised. Three prototypes of the WT-Bird system have been build and tested in the field at different turbines. (Chapter 6)

Finally, Task 4 has been defined and executed which included reporting and writing of conference papers [24], [25], [26].

2. PROOF-OF-PRINCIPLE

2.1 Principle of the WT-Bird System

The principle of the ECN bird collision recorder is depicted schematically in Figure 2.1. At least two microphones, which are mounted at different heights in the tower are continuously recording the sound of the wind turbine and at the same time a camera is also continuously recording the images of the rotor field of the wind turbine. During the recording the sound signal is analysed automatically to detect whether abnormalities with respect to the "normal" turbine sound are present. In case an abnormality is found and when it is recognised as an event of interest (in this case the impact of a bird) the images from the camera and the recorded sound fragment will be safely stored on the hard disk of a personal computer. Subsequently this selected and stored information is evaluated to check whether it was really an impact of a bird, and if a bird was hit to determine the kind of bird.

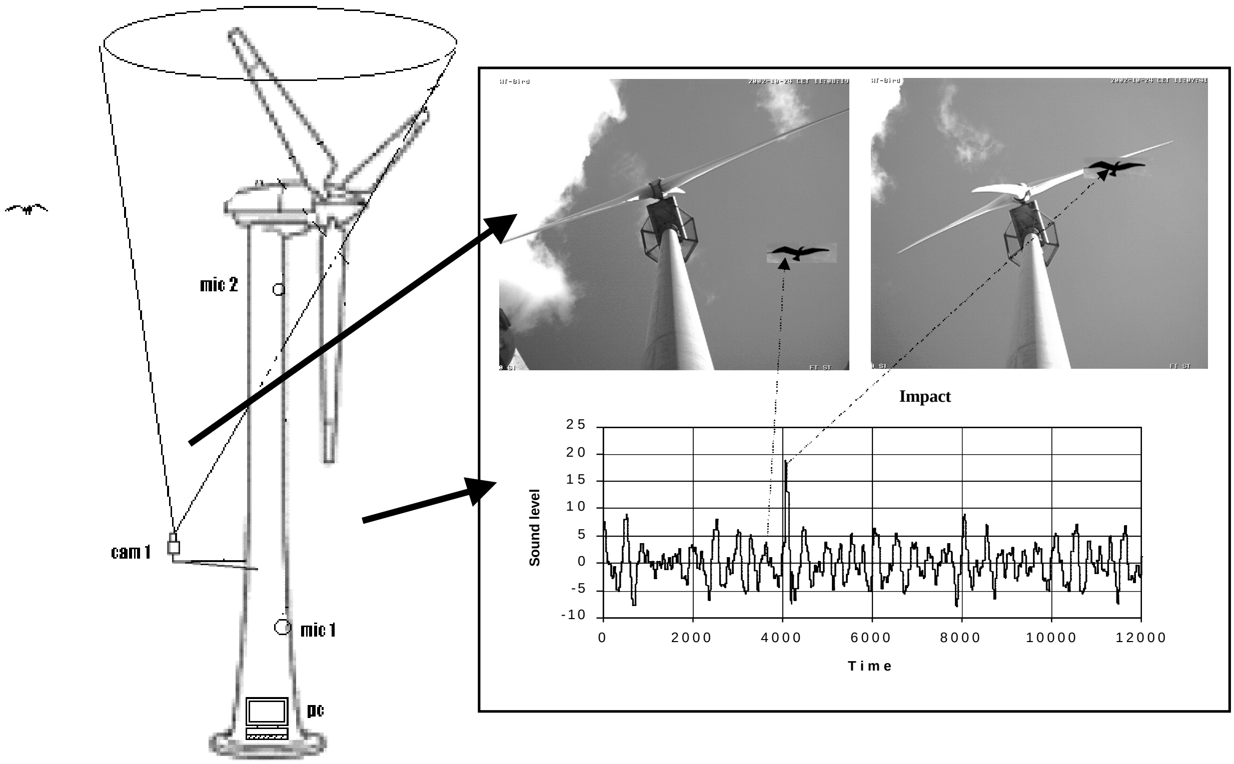


Figure 2.1: *Principle of operation of the bird collision recorder*

2.2 Sound registration

To assess whether the development of a bird collision recorder as mentioned in the previous chapter is feasible and subsequently to determine the route for further development of the system, preliminary experiments have been carried out. The main objective of these experiments was to provide a proof-of-principle of the system. For this purpose it was investigated whether impacts on the tower and the blades, representative for bird collisions can be recognized in the sound signal recorded. Furthermore the capabilities and the limitations of the microphones were examined.

Microphones and a sound recording system were installed in two different wind turbines, viz. a Lagerwey 18/80 kW wind turbine located in the wind farm "Anna Paulowna" near the city of Den Helder [21] and a NedWind 500 kW wind turbine of the Dutch utility ENECO in their wind farm at the Maasvlakte near Rotterdam. The LW 18/80 is a two-bladed turbine with a hub height of 30 m and a rotor diameter of 18 m. The NedWind has two blades, the hub height is 39 m and the rotor diameter is 37 m.

To check what type of microphone is most suited some tests were done with inexpensive contact microphones and spherical microphones.

Two types of test were specified. In the first series of tests small sandbags were thrown against the tower of the wind turbines. The weight of the sandbags was 250 till 1000 gram, which corresponds with the weight of a seagull (saddle-back respectively herring-gull). The second series of tests consisted of shooting tennis balls against the rotating blades using a tennis ball machine. The weight of a tennis ball corresponds with the weight of a sparrow.

2.3 Tests with sandbags

The test with the sand bags were carried out at the LW 18/80 wind turbine. To carry out these tests three sandbags with a weight in the range 250 till 1000 gram were made. An example is given in Figure 2.2.

Figure 2.2: *Examples of the sand bags that were used to mimic birds colliding with the mast of the turbine.*

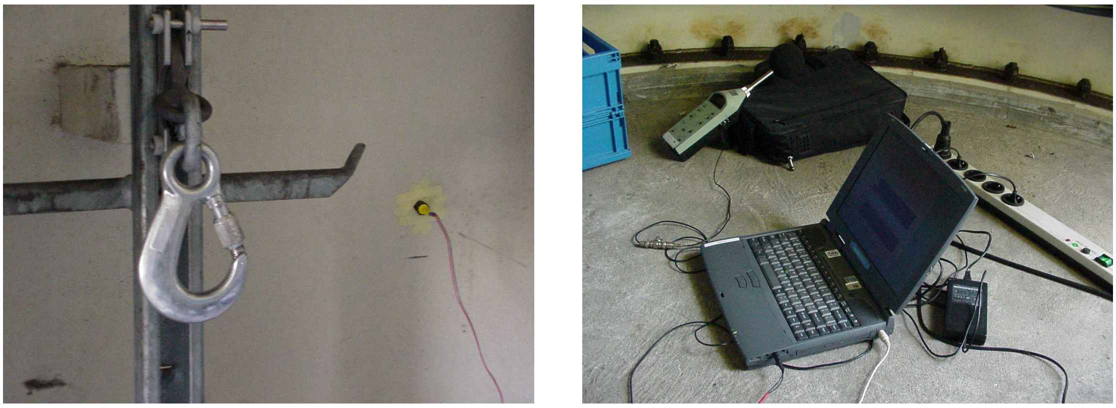


Figure 2.3: *On the left the microphone set-up is shown applying a microphone to the turbine wall (seen on the right in the picture). On the right the spherical sound registration inside the turbine tower is shown*.

These sandbags were thrown from different distances such that the tower was hit on different heights. While carrying out these tests the sound was recorded in two different ways. One with a contact microphone glued to the inside of mast and the other one with a spherical microphone for the registration of the spherical sound inside the tower. Figure 2.3 shows both these forms of sound recording.

The impact of sandbags on the tower can be recognized clearly as can be seen from the sound registration with the contact microphone (see Figure 2.4). The hits are recognised by the two events with high amplitudes of the sound recording. The results with the spherical microphones are not shown here, but are less pronounced.

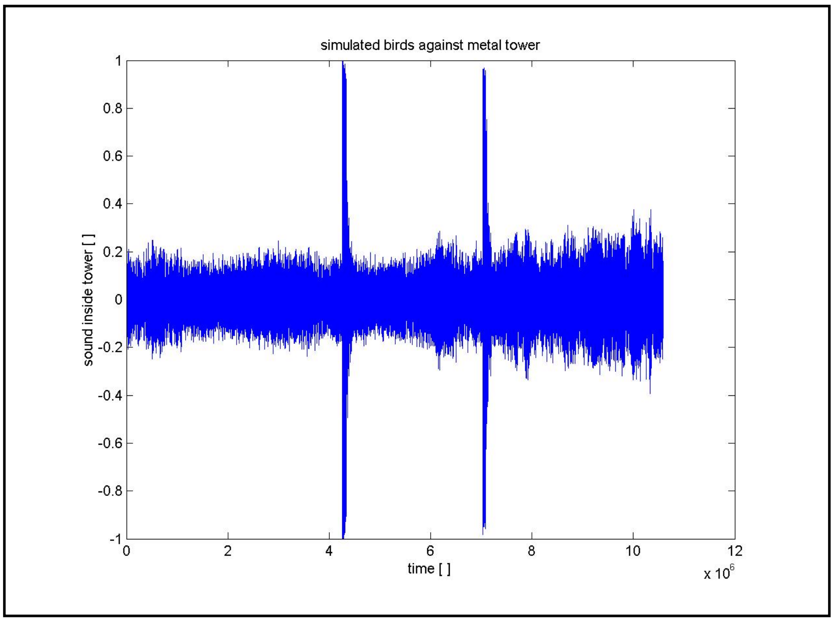


Figure 2.4: *Sound registration with two sand bags against the mast (LW18/80 "Anna Paulowna"). The hits are recognised by the two events with high amplitudes of the sound recording.*

2.4 Tests with the tennis ball machine

Besides experiencing the effect of collisions of birds against the mast of the wind turbine it is also important to know if an impact against the blades can be detected by sound registration. To investigate this, experiments where done shooting tennis balls against the rotor with a traditional tennis ball machine. The selection of a tennis ball was done because the weight of a tennis ball can be compared with the weight of a sparrow. At the same time, shooting tennis balls against blades will not cause damage to the turbine. Bare in mind that it is assumed that when we can detect a sparrow we can also detect heavier (or larger) birds. Figure 2.5 shows the experimental set-up with the tennis ball machine.

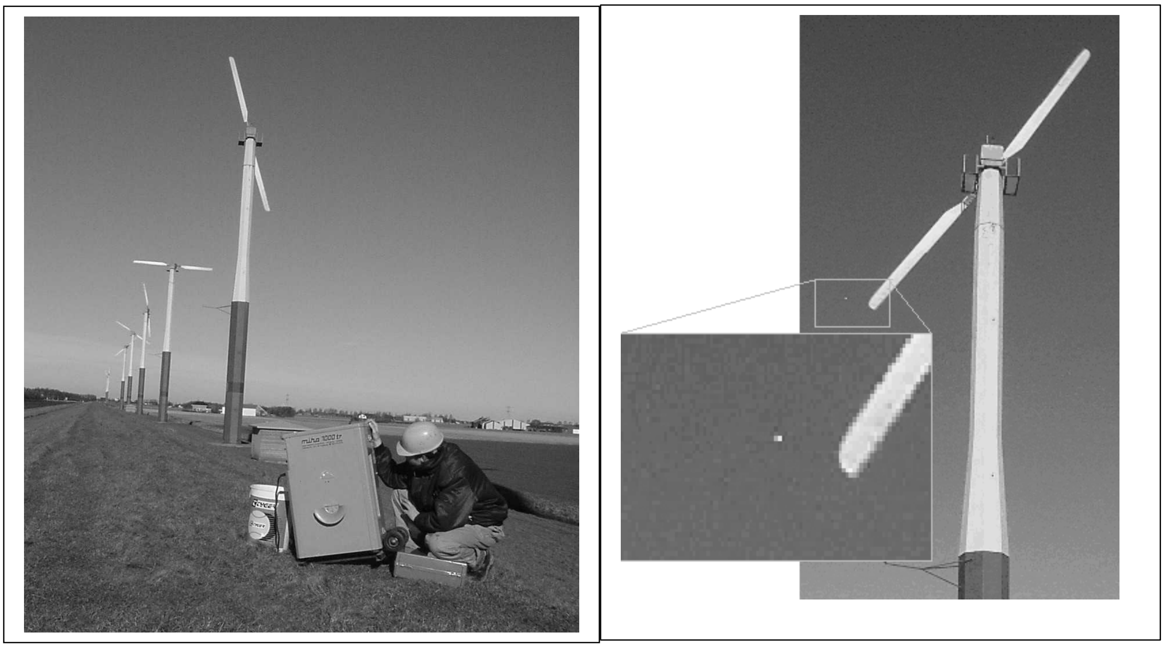


Figure 2.5: *On the left: Tennis ball machine used to simulate Birds (sparrow). On the right: tennis ball hitting the rotor of the wind turbine.*

The described tests are done on both above mentioned turbines, the LW 18/80 and the NedWind turbine. The latter wind turbine has a higher electric power and the hub height is also more comparable (but still not in the range) with the Multi Mega Watt wind turbines. In the left picture of Figure 2.6 the sound registration is depicted of an impact of a tennis ball on a rotating blade of the NedWind turbine.

One can imagine that it is difficult to hit the rotating blades and in practice a lot of balls passed the rotor plane without hitting a blade. Instead sometimes the tower was hit. The right picture of Figure 2.6 shows the sound recording of the event where both the blade was hit once and tower was hit several times. It appears that the type of contact microphone used is not suitable to register the impact of a tennis ball on the tower.

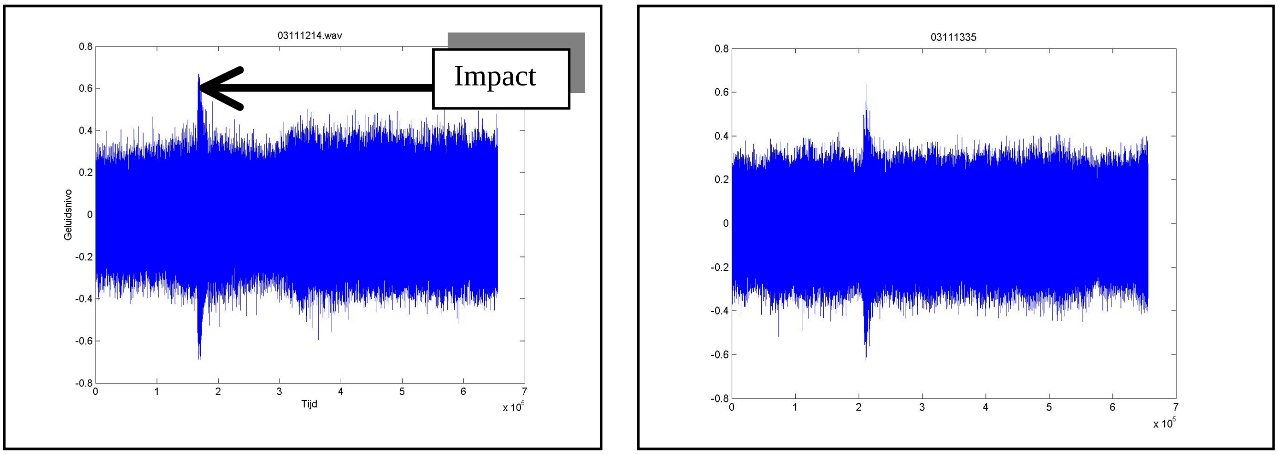


Figure 2.6: *(On the left) Impact of a tennis ball against the rotating rotor blade (WP "Slag Dobbelsteen"). (On the right) Impact of a tennis ball against rotor blade and mast.*

2.5 Conclusions

The tests with the sand bags and with the tennis balls showed that it is possible to detect impacts against blades and the tower using microphones glued on the inside of the tower of the turbine. The spatial microphones are less suitable for recognising impacts. The experiments were done with inexpensive contact microphones, and this is probably the reason that the impacts of tennis balls on the tower could not always be recognised. For future experiments it recommended to improve the signal condition and to use a better quality contact microphones. The microphones made by Schaller might be a good alternative, not only with regard to quality but also with regard to the cost of the microphone.

It should be noticed that the results are obtained with wind turbines that are much smaller than the Multi Mega Watt wind turbines installed nowadays. It is expected that impacts on the tower of the large turbine still can be recognised. However it is not clear whether contact microphones in the tower are still suitable to recognise impacts on rotating blades of the large wind turbines. This should be investigated, and possibly the blades have to be equipped with microphones also.

Based on the results obtained so far it can be stated the bird collision recorder has potency and it is justified to continue with the further development of the system [23].

3. FUNCTIONAL AND TECHNICAL SPECIFICATIONS

This chapter describes the technical and functional specifications of the bird impact detection system as it should be developed. The required specifications are made after internal discussions at ECN and discussions with ornithologists and owners of wind farms [22]. After a general description, the different components of the system are described in more detail.

3.1 Functional specifications

The functional specifications are dealing with two aspects of the system, viz.:

- observation of bird collisions, or how and what collisions should be detected;
- functioning of the hardware of the system, or what are the components of the system and how should it looks like.

3.1.1 Functional specifications regarding bird collisions

The functional specifications of the system regarding bird collisions are the following:

1. The system should count bird impacts;
2. Bird impacts should be detected by sound recording;
3. Bird impacts should be observed both against the mast and the rotor;
4. The system should discriminate between several operational sounds;
5. The system should be able to register images around the rotor of the wind turbine;
6. Image recording should also be done during the night;
7. No interaction with radar detection is allowed;
8. The system should be designed for one wind turbine but it should be made modular so it can be used in a wind farm;
9. Recognition of the bird (species) will be done manually at first, later on with image analysis.

These specifications lead to a system that detects most bird collisions without intervention of operators as good as possible against reasonable costs.

3.1.2 Functional specifications of the bird impact detection system

The system should be affordable, robust and automatic. Maintenance should be easy and limited. ECN research has lead to the following functional specifications of the bird impact detection system:

1. The system should be made with commercial available PC-components;
2. The system should record both sound and image recordings and store them on the hard disc of the PC. By a data connection it should be possible to retrieve the stored data;
3. The system should operate (with a minimum of six months) without any interruption;
4. Operation of the system should be possible from a distance;
5. The system and the used components should operate under offshore conditions. This puts high demands on both the cover and protection of the different components;
6. This system should be self starting after a power dip;
7. The system should notify the operator when the hard disc is getting full (fail-safe)
8. The system should be designed modular and flexible (plug-and-play).
9. Usage of the system in a wind farm should be done by means of a network.

3.2 Technical specifications

To be able to meet the functional specifications as described in the previous paragraph the technical specifications were defined as described in the next paragraphs. Difference is made between hardware and software specifications. As mentioned before the sound registration is used for the detection of a possible collision and a combination of sound and images is used to evaluate the event. For this purpose the system is equipped with two microphones and one camera. The microphones are located inside the tower of the wind turbine at two heights: at the tower bottom and at 2/3 of the mast length.

3.2.1 Hardware specifications

This paragraph describes the specifications of the system as well as its most important components.

Requirements with respect to the PC

The PC system should meet the following requirements:

1. The system will be built based on a (commercial industrial) PC. Minimal Pentium III / 256 Mb RAM. Since the system is intended for long time operation a reliable system should be used;
2. PC should be equipped with a CD-writer (CD-RW);
3. The PC should contain a sound card on the motherboard (for the two microphone option). The sound card should be 16 bits;
4. De PC should have a minimal hard disc of 40 Gb;
5. The PC should be equipped with a (minimum) of 120 Gb removable hard disc (for saving sound and images);
6. The PC should be equipped with a GSM for data transport and quick control (or modem);
7. PC should have a network card for connecting to a local network;
8. The system should be self started so that it recovers after power dips;
9. The PC should be impassive for EMC (or other external disturbances). EMC problems are known to be quite common in wind turbines;
10. PC should have minimal two USB (2) ports for quick data exchange;
11. PC should have firewire for quick data transport;
12. The system should be equipped with minimal Windows NT / Windows 2000 or Windows XP professional. The reason for this is that we should avoid possible obsolete software;
13. The system should be save for outside influences, such as abuse from hackers and others.

Requirements with respect to sound registration

The system of sound registration should meet the following requirements:

1. Sound registration inside the wind turbine is done with two microphones (including a pre-amplifier). Frequency characteristics of the microphones are 10 Hz .. 40 kHz (-3dB);
2. Sound registration is done with a standard 16 bits sound card;
3. Since one of the microphones is located at around 2/3 of the hub height long cables are needed. Therefore balanced lines are required and to establish this a microphone pre amplifier is needed;
4. When sound recording in blades is proven to be necessary, care should be taken on the data transmission. Whether a slipring is installed, or computer capacity in the blades together with a radio link for the transmission of a trigger, communication from the rotating blades tot the tower is necessary.

Requirements with respect to image recording

The system of image recording should meet the following requirements:

1. Camera should be suitable for outside usage (also offshore) because they are placed outside the turbine;
2. Camera should have night vision in order to be able to detect birds at night;
3. Resolution minimal 640*480 during day and night sight;
4. As long as the camera's are not capable of creating a MPEG data file ("video film") they should be able to make a minimal 2-5 frames per second (fps). This to create afterwards with special software a MPEG data file;
5. The camera should be able to put images through a network to the hard disc of the PC;
6. An external light source could be necessary. The emitted light should be in the infrared region so that birds are not attracted to the turbine.

3.2.2 Software specifications

With respect to the software the following requirements are listed:

1. The software should be able to record sound and pictures;
2. The software should be able to analyse the sound recordings;
3. The software should distinguish incidents and "normal" turbine sounds from the sound recording by the two microphones;
4. The software should be able to send an SMS-message to a mobile phone in case of an impact;
5. The software should be self starting after a power dip;
6. The software should be able to present recorded impacts;
7. The software should be documented and relatively inexpensive;
8. The software should be save for outside abuse.

3.2.3 Requirements with respect to the environment

Components of the system will be placed under different environmental conditions like salty surrounding, EMC, temperature fluctuations (-15° till +40• outside temperature), vibrations, rain, hail, fog etc. Measures are necessary to protect the PC and the different components like microphone and camera's. Special actions should be taken to measure temperature and other climate conditions to prevent freezing en condensation. These requirements will also determine the usage of different connection mechanisms like glue etc. For this project no special work has been carried out with this respect.

4. RECOGNITION OF BIRD SPECIES

4.1 Introduction

For determining the different bird species under all weather and visibility conditions, a cheap and robust camera has been selected. It was decided to start the research with a camera of Mobotix AG, see Figure 4.1. Although this camera is used mainly for surveillance applications it has a lot of features which are required for the bird collision recorder also. The Mobotix camera is waterproof and can be used outdoors, it has a dual lens camera so that it can be equipped with day and night lenses, and it uses standard web browser technology so that it can easily be connected to a computer network for image storage.

Figure 4.1: *Mobotix camara*

The resolution of the images is generally 640 * 480 pixels. To avoid condensation of water and freezing, the camera is equipped with a heater. Depending on the requirements, the camera can be equipped with different lenses:

- lenses for the daytime with a focal length of 42, 72 or 150 mm;
- lenses for the night time (called “low-light lens”) with a focal length of 48 or 35 mm.

To investigate to what extend the images recorded by the Mobotix camera are suitable for recognition of birds a series of test with the camera have been carried out. The objectives of these tests were:

1. To check the resolution of the camera. This is done to have a perception of what actually can be seen on the images and how many pixels on the image cover a bird.
2. To examine the capabilities of the low-light lens during day light. Starting point was that the camera had to be equipped with a regular lens for daylight and a low-light lens for the night time both covering the same area. However there were some indications that the low-light lens could provide reasonable pictures during daylight also. In case a low-light lens is suitable for daylight we would have the opportunity to use two low-light lenses, so that for instance the covered area could be increased.
3. To check how the camera operates under different weather conditions, especially during the night.
4. To check what the effect will be of adding an IR lamp during night recording.

4.2 Check of the resolution and low-light lens

In order to check the resolution of the camera under different conditions four boards with different dimensions were made. As birds can be colored dark or light the boards were painted with a white and a brown side. This way, a total number of eight different configurations are tested to get a better understanding of the resolution of the camera. The dimensions of the boards are given in Table 4.1.

Table 4.1: *Dimensions of boards*

Board no.	Dimensions
1	25 * 8.5 cm
2	50 * 17 cm
3	75 * 25 cm
4	100 * 33 cm

The boards were placed on a five meters high mast and at several distances pictures were made. The distances were 20, 40, 60, 80, 100, 120 and 140 meters. The boards were placed on a mast to obtain a more realistic picture with respect to birds flying in the sky. The weather conditions during the test are specified in Table 4.2.

Table 4.2: *Weather conditions during the test.*

Time	By day
Weather conditions	During the morning there was a clear sky. During the afternoon light clouds emerged. Overall: 1/10 clouds
Mast height	5 meters (from bottom of pole till the bottom side of board
Temperature	± 21º
Wind Speed	• 4 m/s

As an example the pictures of board 4 at a distance of 20 and 140 m are shown in Figure 4.3; the left picture is the result of the low-light camera (indicated N), the right picture is the result of the normal camera (indicated D). For each image, the number of pixels a board represents on the image is counted and compared with the theoretical value according to the specifications of the camera. The results are given in [27] and the following can be concluded from these results.

- It appears that quality of the images taken with the regular lens are better than those taken with the low-light lens, especially when there are no clouds. To prevent that information is lost during daytime a regular lens should be used. Hence it is recommended to equip the camera with a regular lens and a low-light lens.
- For the regular day lens the counted pixels do agree quite well with the theoretical value. Slight differences can not be avoided. On the one hand the counted number of pixels is always an integer value and on the other hand due to the visual interpretation of the image. The latter is explained in Figure 4.2, showing an enlarged part of the image of the white board 4 at a distance of 140 m. We determined this board to be of size 5 x 2 pixels. However it is also reasonable to say that 7x3 pixels can be distinguished.

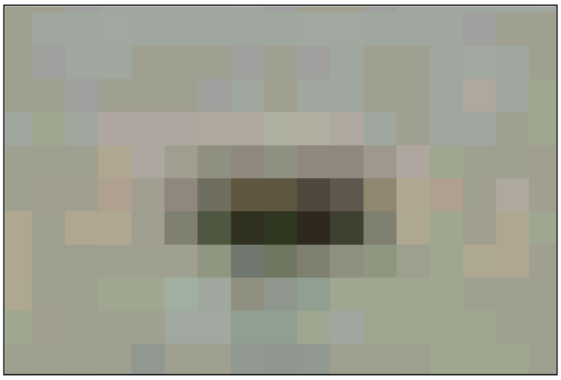
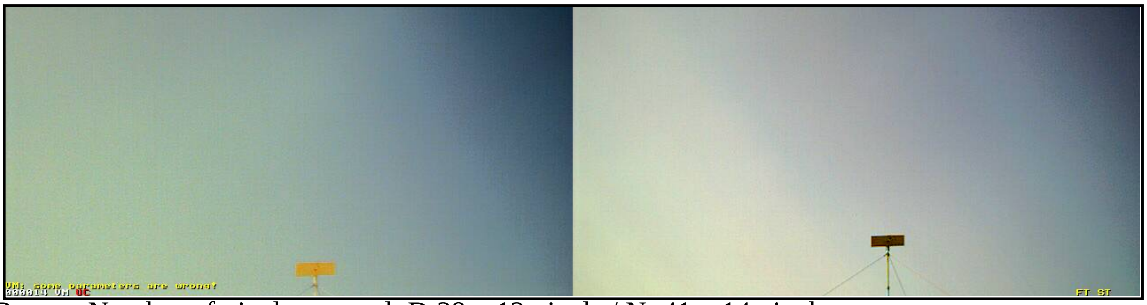


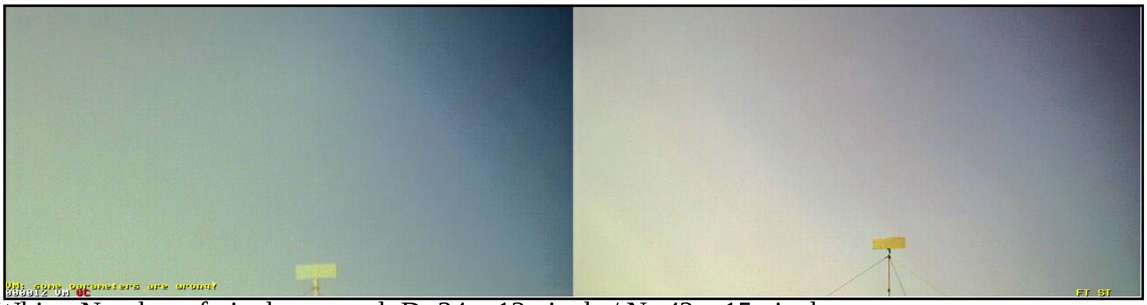
Figure 4.2: *Enlarged image*

Board 4

Board 4, 20 metres:



Brown; Number of pixels counted: D:38 x 12 pixels / N: 41 x 14 pixels



White; Number of pixels counted: D: 34 x 12 pixels / N: 42 x 15 pixels

Board 4, 140 metres:

Brown; Number of pixels counted:D:5 x 2 pixels / N: 5 x 2 pixels

White; Number of pixels counted:D:5 x 2 pixels / N: 4 x 2 pixels

Figure 4.3: *Pictures of board 4 at 20 and 140* m

4.3 Checking weather conditions

This test was performed to investigate how the camera configuration handles different weather conditions, especially during night time. The same boards are used as in the previous experiment. In the following table we find the conditions under which the tests were done.

Table 4.3: Conditions during the test

Time	21:00 hr until 24:00 hr
Weather conditions	At 20:30 hr there were some light clouds in the sky which became less. Overall: 1/10 clouds
Mast height	5 meters (from bottom of pole till the bottom side of board
Temperature	± 25º
Wind speed	• 4 m/s

Images:

Images of 4 different boards with two colours (brown and white) were made for the following distances: 20, 40, 60, 80, 100, 120 and 140 metres. It appears that during the night when no or only very limited external light is available, the boards could not be recognized on the images. So during night external lightning is required.

Some exploring tests have been made with a 14 Watt IR-light with a wavelength of 940 nm. On the shorter distances, up to about 40m, the quality of the images did improve. However due to the limited capacity of the lamp no improvement was found at the larger distances. Further research is needed to select a configurations of one or probably more IR lights, which is able to cover the whole rotor of a larger wind turbine. Special attention should be given to the wave length of the IR-light, because it is not clear to what extend birds are sensitive to IR light.

4.4 Checking external illumination with IR light.

In the previous sections images of static boards were considered. When recording birds we have to deal with moving objects. Especially at night it might be complicated to select a suitable exposure time for the camera. As the light intensity is low the exposure time should be high, but because a bird is moving just a short exposure time is required. So also for the situation with moving objects the selection of external lightning is important. To get a good impression of these problems image recordings were made of a small rotating wind turbine located at the ECN test site. The turbine was illuminated by a 14 Watt IR-light, as shown in Figure 4.4

Figure 4.4: *IR external illumination lamp*

For field tests the camera is provided with a housing to protect the system. Images were made with and without additional housing and it was found that the window in the housing does not have an effect on the quality of the images. Figure 4.5 shows the camera housing as intended to be used in future projects. The recordings made with and without housing are given in Figure 4.6.

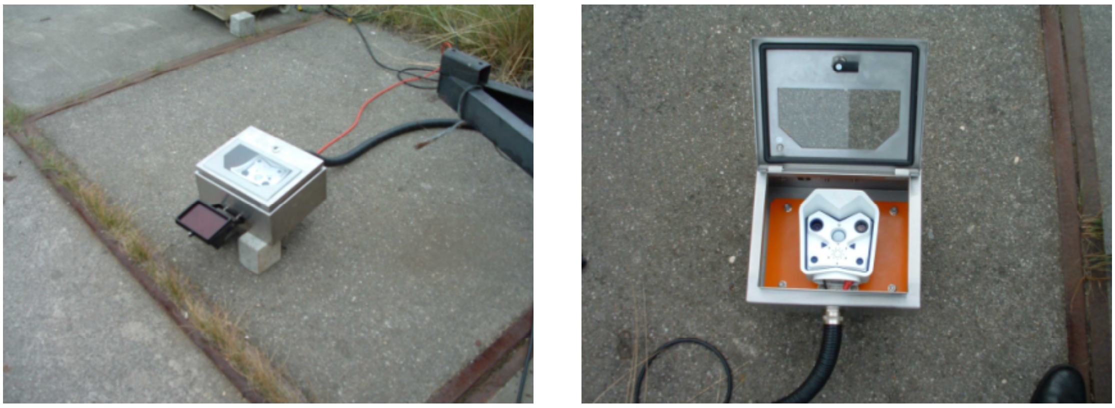


Figure 4.5: *Camera housing used for night tests with the IR light source mounted on top*

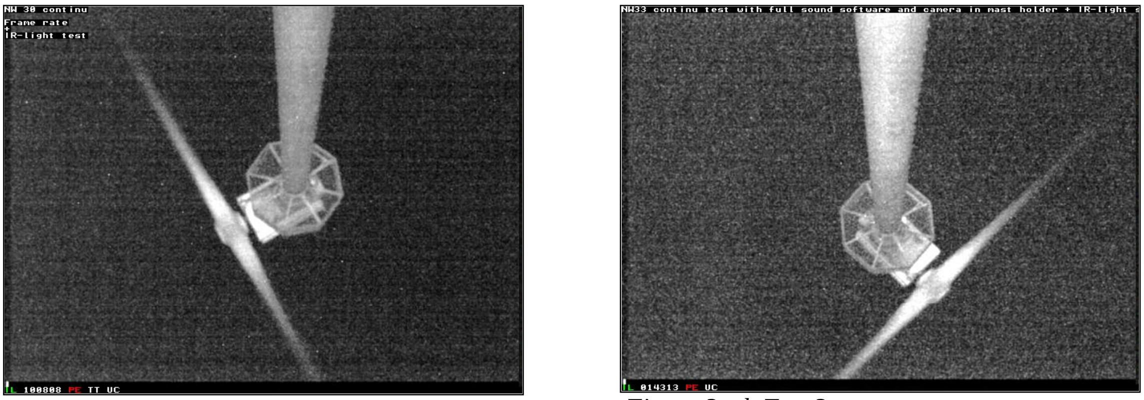


Figure 4.6: *Test with external IR source, left without additional housing, right with additional housing.*

A point of attention is the exposure time used during the night recordings. For the images shown the exposure time is determined automatically with a maximum of 1/2 second. This could possibly lead to the situation that a bird is seen as a line due to the large exposure time, as indicated in Figure 4.7, where an object (probably a bird) is passing the turbine. Further tests with the camera should indicate if an exposure time of 1/10 or 1/5 leads to better results.

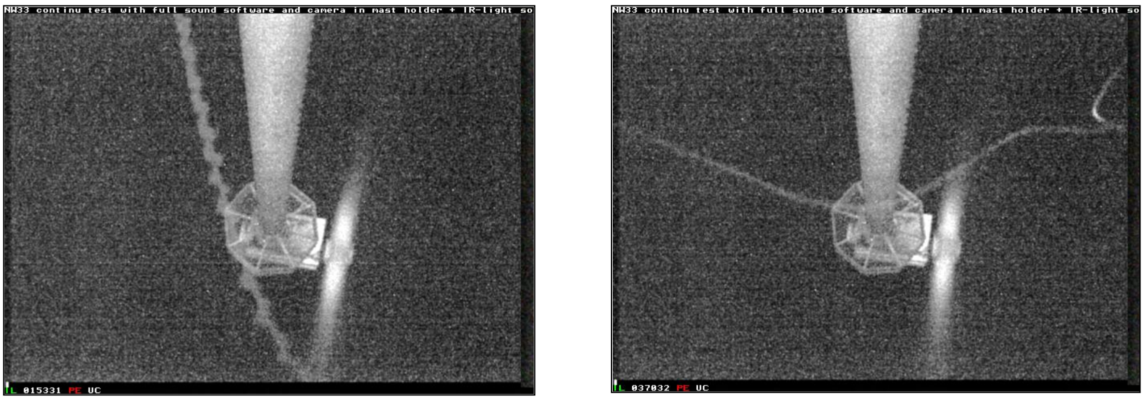


Figure 4.7. *Night recordings where moving objects passed the turbine, probably birds*

5. DETECTION OF IMPACTS AND TRIGGERING

5.1 Detection of Impacts

In order to determine an algorithm for detecting bird impacts and triggering, numerous sound recordings, analogous to the time series shown in Figure 2.4 and 2.6, have been made and analysed. Not only recordings of dummies have been made. The major amount of sound recordings consisted of recordings of operational sounds and background noises. From the analysis it appeared that the following configuration gave the best results for the turbines at which the proof-of-principle tests were done: Lagerwey LW 18/10 and NedWind 500 kW.

- One microphone should be mounted at the bottom of the tower, a second one around 2/3 of the hub height. Impacts caused by slamming doors etc. do have the same order of magnitude as colliding birds. But, if the impact of the lower microphone is higher, it is unlikely that the impact has to do with a collided bird.
- A peak in the sound level is the initial trigger for the image recording as soon as it is at least X % higher than a threshold value that is based on the average amplitudes of the sound recording. In this case “X %” is a value which is strongly dependent on the type of turbine and its background noise and on the type of bird and the way it collides with the turbine. In fact, the factor “X” needs to be determined for all different types of turbines immediately after the installation of the WT-Bird system. To decide if this initial trigger is a real trigger or a false one, further detailed analysis of the sound signal is being done, e.g. a check on the energy content of the signal.

As already mentioned, numerous sound fragments have been analysed but a microphone configuration and an algorithm that works satisfactorily under all circumstances has not been developed. During the field test it appeared for instance that choosing a low value of “X” gave too many false triggers, which could not be eliminated by further analysis of the sound signal. A too high value will probably lead to missing impacts but this situation can hardly be verified without ornithological research.

Furthermore, few more advanced methods of data analyses have been tried, e.g. Fast Fourier Transformation (FFT) but again this did not lead to good results.

The project team has concluded that the current method for triggering needs to be improved.

- More impacts of dummies or real birds need to be collected to obtain better insight in the different manners of colliding and the magnitude of the sound level.
- There is still no evidence that the method for triggering works also for bigger Multi Mega Watt turbines.
- More detailed analyses of the recorded sound signals and probably more sound recordings of turbines are needed to improve the algorithm which decides whether the initial trigger is real or false.

5.2 Software

The chosen algorithms have been implemented. The software of the WT-Bird system has two major tasks. One task is to record, analyse and store the sound data while the other task is image recording and storing.

The sound recording software is implemented in Matlab. The software as used in the prototypes, is for commercial use not the most optimal form. For a more definite version the software should be written in a more general language (like the programming language C). Figure 5.1 shows a general overview of the software developed for this project.

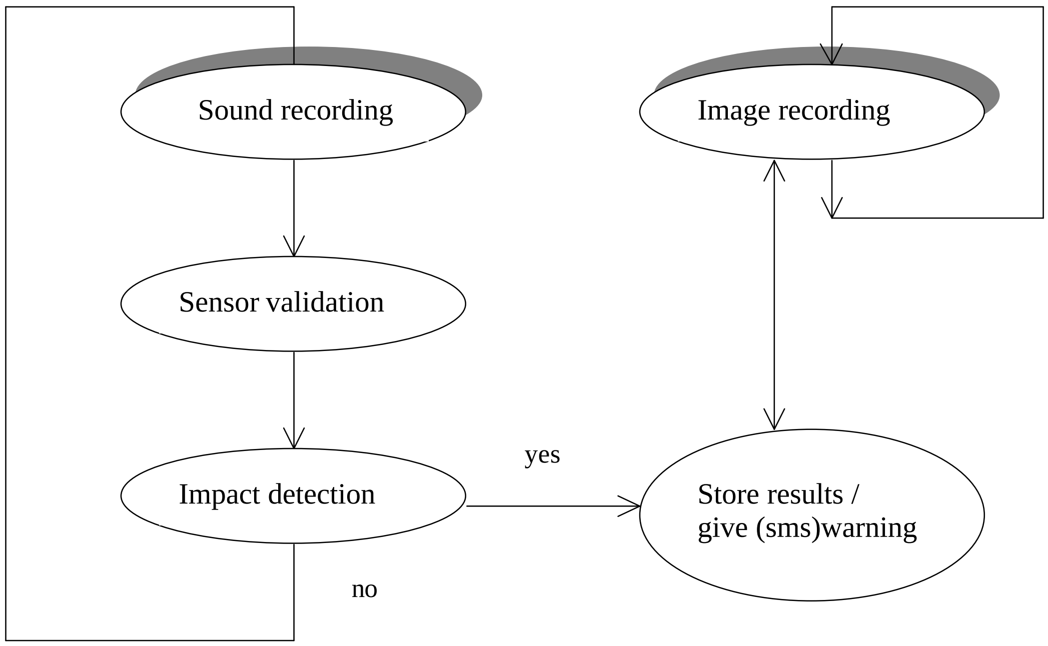


Figure 5.1: *Principle of the WT-Bird software*

The software has the following major tasks:

1. Sound recording and analysis.
   - The first task in sound recording is recording and creating 1-minute sound fragments. After a file is created this file will be analysed for impacts and, depending on the results, written to a special location on the hard disc. After that a new 1-minute sound fragment is recorded. This is a continuous process until the process is stopped. The length of the sound fragment can be adjusted but we found out that longer sound fragments cost to much computer-time and gaps between data processing will harm the process.
   - After the sound recording a module checks if the sensors are working properly. This checking is done for both the sensors recorded in the file. If a sensor has a malfunction a warning can be provided (via SMS) to the users. Although this function is available, it is not in operation at the aforementioned sites.
   - The most important module is the module for impact detection. What this module does is checking if a threshold level is exceeded (compared to background noise) and if so, is the energy in the peak different for both sensors. If the sensor near the tower top gives a higher energy then near the tower bottom, the impact will be considered as an impact to be investigated further. So we make a distinction between a (sure) impact and a possible impact. Depending on this distinction the files will be written to a specified location on disc.
   - Store results, provide warnings and clean-up. This module does in fact three things. First of all, depending on the sort of determined impact the 1-minute sound fragment and the image files (2 frames per second) will be written to a subdirectory on disc. The subdirectory will have a time stamp so it can be traced quit easily. Furthermore, the module will send an sms-warning to the operators so that they can check if an impact occurred. At this moment only when the software decides that it is a real impact the warning will be send. This module is written in VisualBasic. Furthermore, the module will clean old sound fragments and image recordings (for the time being we use a buffer of three days).
2. Image recording and storing. As mentioned earlier the camera is a complete network PC. It has the possibility to store images on a local disc or sends the images via the network to the host PC. For our application we used the camera so that it sends (via ftp-protocol) the

images to hard disc on the host PC and if an impact occurred the images will be written, just like the sound fragment, to a dedicated subdirectory. The number of files saved depends on the selection. We selected for our tests three minutes of image files (before and after the impact). This was done to see also the flight of the bird before the collision.

Some other remarks regarding the used software. As mentioned earlier the camera at this moment provides single JPG-files. JPG-files are well known for their application of graphical usage. To make the analysis of the pictures more easy we used a freeware software package that enables us to make a movie file (mpeg). This software package should be incorporated in the definitive version of the software.

6. SYSTEM DESCRIPTION

6.1 Principles

Based on the results of the camera tests and the tests with triggering, a prototype has been built which met the specifications in Chapter 2 to the extend possible.

For the prototype, it has been decided to choose a normal PC as the basis for the WT-Bird system, together with a sound card, microphones and one camera. To anticipate of future needs from ornithologists, the system has been designed as such that the number of microphones and cameras can be extended.

Two examples of possible camera configurations are shown in Figure 6.1. The left-hand situation is usually the default situation. It uses two microphones in the tower and only one camera mounted at the tower foot that covers the entire rotor surface. If the ornithological research requires more details, the system can be extended up to four microphones and four cameras; if necessary with different characteristics. Three microphones and two cameras can be placed at strategic positions in the right hand situation to obtain more details of the birds. If birds pass by at lower altitudes (a situation that regularly occurs offshore), a camera can be focussed on lower parts of the turbine.

On the right side of Figure 6.1 we see a schematic view where three cameras are placed. The lower camera is directed towards other wind turbines in a wind farm, so that it can monitor that turbine. In addition, this could be of convenience for the operators of the wind farm, for example to monitor shipping etc. Another camera is aligned to monitor the wake of the turbine, where it is known that birds can be victims of high turbulence. However, there will be no trigger in these cases.

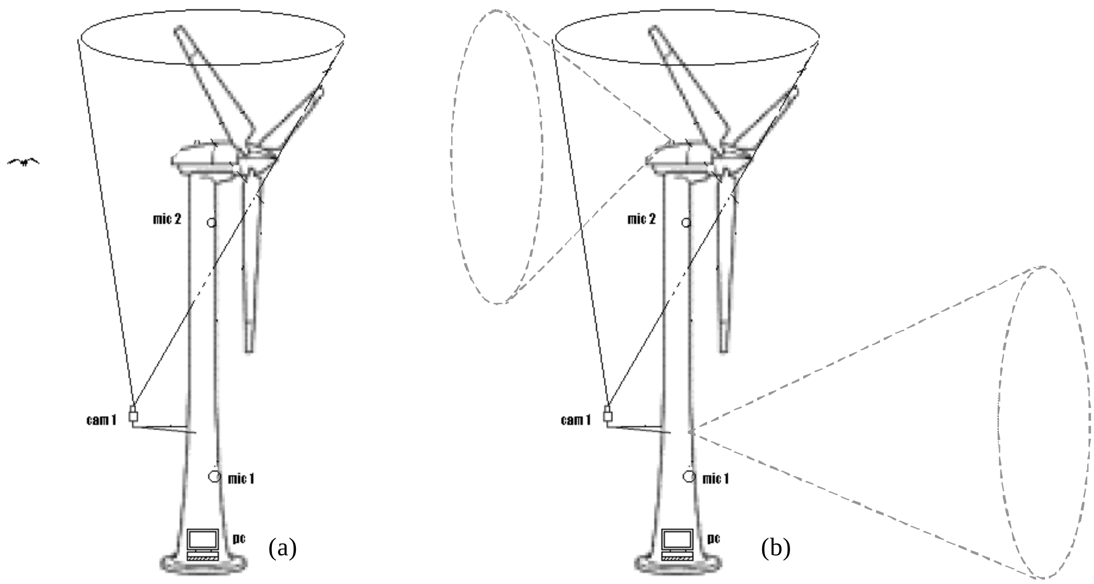


Figure 6.1: *Different possibilities for placing microphones and cameras*

As both the camera and PC are network components a small network with a hub has been created. During the different tests a four and a eight port hub/switch have been used. By using a standard PC network it was not only possible to connect more than one camera, but also to transfer very quickly data from the camera tot the host-PC. Transfer is done by the standard network protocol TCP/IP. To implement this transfer we use a commonly available ftp-server software package.

The layout of the modular set-up is given in Figure 6.2.

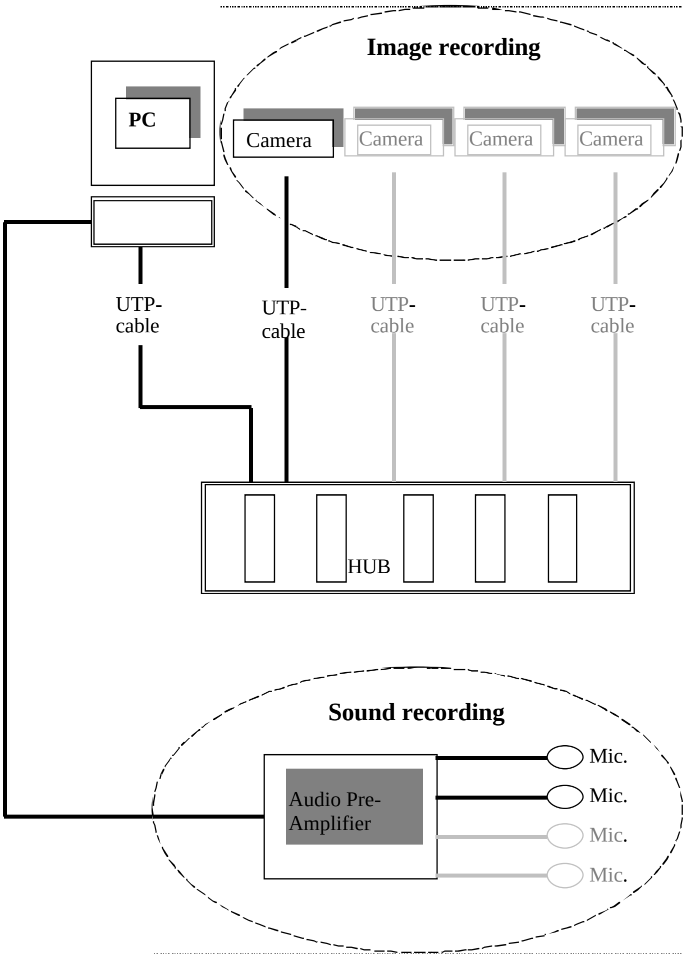


Figure 6.2: *Schematic overview of the modular network configuration*

6.2 Sound and Microphones

Based on the findings in Chapter 2, two contact microphones have been selected that meet the specifications in Chapter 3. One is placed near the bottom of the tower and the other one in the upper half of the tower. The total sound recording also includes a pre-amplifier and a sound card in the PC. The application of a microphone to the tower is shown in Figure 6.3.

Figure 6.3: *Microphone applied to tower*

6.3 Camera and Housing

The camera is a Mobotix camera with two lenses (see also Chapter 4, Figure 4.1). In the task “development of the system”, emphasis has been put on the development of robust housing, easy mounting on the mast, and mounting of the IR light source.

In fact, the camera is designed for outside use and to withstand all weather conditions. As opposed to the normal applications (surveillance) the camera is now placed vertically instead of horizontally. Three different types of housings have been designed and tested. All housings have been made of stainless steel.

1. Horizontal with mirror
   The first housing has been designed with keeping in mind that the best position is horizontally. The housing uses a mirror placed under an angle of approximately 45 degrees (see Figure 6.4). The housing should be placed on a flat surface (ground, roof of transformer housing, etc.) and the angle can be fine-tuned at location. Placing the mirror under the angle of 45 degrees had the advantage that rain and debris does not remain on the surface. In practice it appeared that animals (snails, mice) and grass sometimes influenced the visibility in a negative way if the camera was placed on the ground. The fact that mirror images were recorded was not considered as a problem.
2. Vertical without mirror
   The second housing was somewhat simpler (see Figure 6.5). The camera is now placed vertically. Again the glass surface is placed under an angle to avoid rain and debris to remain on the glass. This housing also should be placed on a surface. From the tests it was learned that the glass surface had to be covered with a special water-repellent coating. This finally led to better images, even during and after rain showers.
3. Vertical at tripod
   The more or less final version of the housing is based on the experiences with the “ground placed” housings. The “ground placed” housings were easily accessible for modifications and improvements. From interviews with ornithologists and potential customers and from

the field tests it was concluded that the best position of the camera is 5 to 15 metres above the ground level. The final housing is already shown in Figure 4.5. Figure 6.6 shows the housing mounted on the tripod.

Figure 6.4: *Camera housing with mirror*

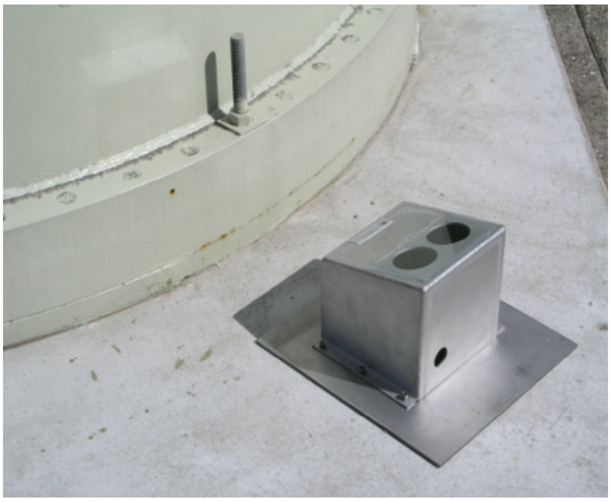


Figure 6.5: *Camera housing without mirror*

Figure 6.6: *Camera mounted at tripod*

6.4 Computer

For the different tests a standard PC (Intel Pentium III processor, / 256 Mb RAM) with 16 bit sound cards and an interface for the camera was used (see Figure 6.7). The PC is equipped with an exchangeable hard disk, 2 USB ports, and a firewire for data transfer.

Figure 6.7: *Basic build-up of the PC-system for testing*

7. OPERATIONAL EXPERIENCES WITH THE WT-BIRD SYSTEM

Based on the results of the proof of principle two systems have been build and placed at two sites in the Netherlands. One system has been placed in a single Vestas 225 kW wind turbine in the city of Den Helder. The other system has been placed at the roof of a control building at the foot of a 1.65 MW Vestas wind turbine of the onshore wind farm Waardtocht in the northern part of the province Noord-Holland.

7.1 Vestas V29 in Den Helder

In the city of Den Helder close to swimming pool “De Schots" a Vestas V29 wind turbine, see Figure 7.1, has been equipped with a WT-Bird system. This was the first system used for long term tests. The wind turbine is owned by wind turbine co-operation “De Eendragt”. In Figure 7.2, the camera view is given. The camera housing that was used was the vertical one without the mirror, see also Figure 6.5. On a regular basis, the site has been inspected to search for collided birds. Unfortunately, no dead bird was found during the measurement period of seven months.

The system as it was installed operated satisfactorily on most aspects.

- The camera gave a clear view during the day time.
- Dummies have been thrown against the tower and they triggered image recording.
- The number of false triggers was limited to only a few per month by reducing the threshold value. However, it is not clear if a bird collision against the blades can be detected.
- Recorded events could be analysed, but the method for analysing JPEG files and sound records should be improved. At present only specialists are able to look into the results.
- Night shots gave no clear images as was already expected from the tests with the camera.
- The camera housing was robust, only one recommendation for improvement was given, namely to use special water-repellent coating.
- The software appeared to be robust. After loss of grid, the system appeared to be self-starting.

Figure 7.1: *Location "De Schots" in Den Helder*

Figure 7.2: *Camera set-up and view at the Den Helder location*

The system was also installed on a similar Vestas turbine for a short period at a location where more birds pass by. As can be seen in Fig. 7.3, the camera does give a view during the daytime which is clear enough for bird recognition. At this site, a lightning strike has also been recorded by the WT-Bird system, see Figure 7.4. For future developments it is recommended to extend the functionality's of the WT-Bird system a.o. with lightning detection. For offshore wind farms, recorded impacts may drastically use the amount of inspections, and the images can be used to convince insurance companies.

Figure 7.3: *An oyster-catcher passing the wind turbine*

Figure 7.4: *Lightning strike detected by the WT-Bird system during rain*

7.2 Wind Farm "Waardtocht" in Wieringermeer

The second system has been installed at a Vestas V66 wind turbine in wind farm Waardtocht. This wind farm is located in the northern part of the province Noord-Holland (municipality Wieringermeer) and consists of five wind turbines with a hub height of 80 meters. The rotor diameter is 66 meter and the rated power is 1.65 MW, see Figure 7.5. The wind farm is owned by NUON.

Unfortunately, the system could not be installed completely. It was not possible to mount a cable from the PC in the tower foot to the camera outside; a cable hole was missing. Instead, the system has been running continuously with the sound recordings only. Sometimes when ECN personnel was at the site, the camera located at the transformer station was connected manually with an open door in the tower foot. The camera view is given in Figure 7.6. At the end of a measurement period of one month, no impact was detected by the sound recordings.

Figure 7.5: *Wind farm "Waardtocht"*

Figure 7.6: *Camera view of the Vestas V66 wind turbine in Waardtocht*

8. DISSIMINATION OF RESULTS

The results of the project are presented at three international conferences, viz.:
- DEWEK 2002 [24]
- OWEMES 2003 [25]
- EWEC 2003 [26]

Several companies showed their interest and are willing to buy the system, as soon as it is operational.

Furthermore The WT-Bird project attracted a lot of attention from the national and international press. Several radio interviews are given by ECN experts and several articles appeared in newspapers.

Some of the contacts with the press where:
- Radio interview on Radio Noord-Holland (28-02-2003)
- Article in the Schager Courant (03-03-2003)
- Radio interview for Radio 1 program "De Ochtenden" (VARA).
- Article in the "Nederlandse Staatscourant"

Stad & Streek 2 NHD 3/3

Meetsysteem botsingen vogels op windturbines

Van onze verslaggever

PETTEN – Energieonderzoekcentrum Nederland (ECN) heeft een meetsysteem ontwikkeld om vogels die tegen windturbines aanvliegen, te registreren. Dit zou het potentiële gevaar voor vogels beter in kaart moeten brengen dan de huidige methode.

Sinds de opkomst van windmolenparken bestaat de vrees dat vogels zich tegen de wieken van windturbines dood vliegen. Het geplande windmolenpark bij de Afsluitdijk is onder meer om die reden afgeblazen. Tot op heden is er echter weinig bekend over het risico dat vogels lopen. Observaties door vogelaars van vogelslachtoffers op het land rond de turbines leverden niet het gewenste effect.

Daar is met het nieuwe meetsysteem verandering in gekomen, meent het ECN. De detectiemethode is gebaseerd op de geluidsmeting. Met behulp van microfoons, bevestigd op de [illegible]dturbinetoren en bovenop het turbinehuis, kan een 'aanvlieging' worden waargenomen. Een webcamera registreert vervolgens de soort vogel. Biologen kunnen met behulp van dat beeldmateriaal vaststellen om welke vogel het gaat.

Zandzakje

ECN heeft uitvoerige tests gedaan. Onder meer bij een turbine in de buurt van zwembad De Schots in Den Helder. ECN-onderzoeker H. Verhoef verhaalt hierover op de website van ECN.

„Om een botsing van een kokmeeuw te simuleren gooiden we een zandzakje tegen de windturbinetoren aan. Ook schoten we met een tennisballenkanon op de rotorbladen." Een tennisbal is qua gewicht te vergelijken met een spreeuw.

Het nieuwe meetsysteem is volgens het ECN 'relatief goedkoop'. De eerste testen met praktijksimulaties hebben uitgewezen dat het systeem goed functioneert. Eind februari zal het systeem in gebruik worden genomen bij een Vestas-turbine aan de Waardtocht in de Wieringermeer. Ook wil ECN het systeem toepassen op het nieuwe windmolentestpark bij Kreileroord. Hiervoor heeft ECN bij Novem een onderzoeksvoorstel ingediend.

Bovendien hoopt het onderzoekcentrum het systeem uit te proberen bij een windpark op zee, om aan te tonen dat het ook tegen heviger omstandigheden bestand is. „Dan kunnen we zien of windturbines werkelijk gevaar opleveren voor vogels. Dan is het ook mogelijk om bij vogeltrek het windpark tijdelijk stil te leggen en de turbines tijdelijk te draaien, zodat vogels ongestoord kunnen doorvliegen", aldus Verhoef.

9. CONCLUSIONS AND RECOMMENDATIONS

The project WT-Bird has been executed by ECN with the objective to develop and demonstrate a system with which birds colliding against running wind turbines can be detected. The expected result has not been achieved completely. The problems that needed to be solved before building and assembling such a system have been underestimated during the definition phase of the project. Two problems appeared to be dominating and much more complex than expected:

1. Triggering
   Birds can collide against rotors and towers in many different ways. The tests that have been performed with shooting tennis balls against the flat side of rotor blades and throwing and sand bags against the tower do not cover the entire range of possible bird impacts. Secondly, the variety of possible microphone configurations and background noises for especially larger turbines is bigger than originally expected. The determination of a good algorithm for triggering should be further investigated. Within the constraints of the project, more detailed investigations were not feasible.
2. Image recording and recognition of bird species
   Already at an early stage in the project it was decided to use the Mobotix camera a.o. because it had a normal lens and a low-light lens, it could be accessed with commonly used web browser technology, and especially because it was cheap. During the field tests, the shortcomings of the camera became clear. The view during night-time was insufficiently clear for recognition of species. Additional light sources were necessary and the exposure time is too long, leading to too low sample frequencies. A large part of the project has been spent on improving the visibility during night-time but without being completely successful.

To solve these problems, further R&D work is recommended. More tests with dummies against larger turbines should be performed and the tests with cameras should be continued. Moreover, much more long-term field tests should be performed in close collaboration with ornithologists.

The assembly of the prototypes has been carried out in this project successfully. They behaved robust and reliable, and only minor problems have been identified. For the future it is recommended to use industrial PC’s instead of the ones used for the prototypes and to make the system plug-and-play. However, this is part of the further product development, once it is demonstrated that the system indeed works for large turbines. Some practical findings are as follows:

- Special water-repellent coating against raindrops should be used with respect to the protection of the window of the housing.
- Experiences with the two different camera housings led to the conclusion that the solution with the mirror is not desirable. During the tests, it was noticed that there were problems with snails on the mirror.
- External IR illumination is needed for night recording.

Other recommendations for further research are

- The wake of the rotor may disturb birds. These potential bird victims cannot be detected by the WT-Bird system and other methods should be developed.
- When there is fog, there is a bigger change on bird collisions. Since we didn't find any victims with this kind of weather it is not clear what the effects will be on observations. Ornithologists proposed to add an additional microphone outside the wind turbine for recognition of species in addition to the video images.
- It should be investigated if more functions could be added to the WT-Bird system, e.g. detection of lightning strikes and detection of intruders.

10. REFERENCES

Birds and Wind Turbines

[1] Buurma, L.S. en H. van Gasteren, 1989, Trekvogels en obstakels langs de Zuidhollandse kust, 's-Gravenhage

[2] Energieonderzoek Centrum Nederland (ECN), 2001, Projectvoorstel WT-Bird, Petten

[3] Informatiecentrum Duurzame Energie (IDE), 1999, Windenergie & Vogels, Informatiecentrum Duurzame Energie, Arnhem

[4] Jeurink, N. en E. Dönszelmann, 2002, Monitoring van vogels op het NSW, Den Haag

[5] National Wind Co-ordinating Committee (NWCC), 2001, Avian Collisions with Wind Turbines: A Summary of Existing Studies and Comparisons of Avian Collision Mortality in the United States, Washington D.C.

[6] Stichting De Noordzee, 2002, FRISSE ZEEWIND. Visie van de natuur- en milieuorgansiaties op de ontwikkeling van windturbineparken offshore, Stichting De Noordzee, Utrecht

[7] Tucker, V.A., 1996, A mathematical model of bird collisions with wind turbine rotors, Journal of Solar Engineering 118:253-262

[8] Benner, J.H.B., J.C. Berkhuizen, R.J. de Graaf , A.D.Postma en J.H.W. Hendriks, 1993, Impact of wind turbines on birdlife, Rotterdam, CEA Rapportnummer: 9247,

[9] Frisse Zeewind, Stichting De Noordzee, Utrecht, 2002

[10] 40th IEA Topical Expert Meeting, Sven-Erik Thor (co-ordinator), Stockholm, 2002

[11] M.J.M. Poot, A.L. Spaans en S.Dirksen, Risicoanalyse effecten van het Multi Megawatt Testpark in de Wieringermeer op vogels, Culemborg, 2000

[12] A.L. Spaans, J. van der Winden, L.M.J. van den Bergh & S.Sirksen, Vogelhinder door windturbines, Landelijk onderzoekprogramma, deel 1: verkennend onderzoek naar nachtelijke vliegbewegingen in getijdegebieden, Culemborg, 1995

[13] J.E.Winkelman, Vogels en het windpark nabij Urk (NOP): aanvaringsslachtoffers en verstoring van pleisterende eenden ganzen en zwanen, Arnhem, 1989

[14] Gijs van Kuik en Jos Beurskens, Alles in de wind, Petten, 200

[15] L.M.J. van den Bergh & A.L. Spaans, De mogelijke hinder van een 8 MW windpark langs de Zuidermeerdijk (NOP) voor vogels, Wageningen, 1993

[16] C.J.M. Musters, G.J.C van Zuylen en W.J. ter Keurs, Vogels en windmolens bij de Kreekraksluizen, Leiden, 1991

[17] J.C. Berkhuizen en M.E.J. de Graaf, Vogelschade door windturbines (*verslag van de workshop, gehouden op 5 juni 1987 te Utrecht i.o.v. NEOM),* Rotterdam, 1987

[18] William R. Evans, Applications of Acoustic Bird Monitoring for the Wind Power Industry, *National Avian-Wind Power Planning Meeting III*,(USA), 1998

[19] Susanne Ihde und Dr. Erika Vauk-Hentzelt, Vogelschutz und Windenergie, Osnabrück, 1999

[20] Pforr / Limbrunner, Thieme's Vogelatlas. De Europese broedvogels (deel 1 & deel 2), Zutphen, 1981

Design, development and application of the WT-Bird system

[21] Hans Verhoef, Erik Korterink en Rob Nijdam, WT-Bird "Verslag test op de Maasvlakte met het vogelinslagdetectiesysteem", Petten, 2002, ECN memo: ECN-Wind Memo-02-012

[22] Hans Verhoef en Erik Korterink, WT-Bird "Functionele- en technische specificaties van het vogelinslagdetectiesysteem (versie 1.0)", Petten, 2002, ECN memo: ECN-Wind Memo-02-029

[23] Hans Verhoef, Erik Korterink en Toine Curvers, WT-Bird "Onderbouwing ten behoeve van Go /No-Go beslissing na fase3", Petten, 2002, ECN memo: ECN-Wind Memo-02-030

[24] J.P.Verhoef, C.A. Westra, H.Korterink, A. Curvers, WT-Bird "A novel bird impact detection system", Petten, 2002, ECN rapport: ECN-RX--02-055 (*Paper presented at DEWEK 2002 Conference, Wilhelmshaven, 23-24 October 2002)*

[25] J.P.Verhoef, C.A. Westra, R.J. Nijdam, H.Korterink, P.J. Eecen, Offshore wind energy and noise monitoring, Petten, 2003, ECN rapport: ECN-RX--03-012 (*Paper presented at OWEMES 2003 Conference, Naples (Italy), 10-12 April 2003)*

[26] J.P.Verhoef, C.A. Westra, P.J. Eecen, R.J. Nijdam, H.Korterink, Development and first results of a bird impact detection system for wind turbines. Petten, 2003, ECN rapport: ECN-RX--03-035 (*Paper presented at EWEC 2003 Conference, Madrid, 16-19 June 2003)*

[27] H.H. Scholtens, *Testrapporten: Testfield test 2 en Testfield test 3*

	Date: November, 2003	**Number of report:** ECN-CX--03-091
Title	WT-Bird: A low cost solution for detecting bird collisions	
Author(s)	J.P. Verhoef, P.J. Eecen, R.J. Nijdam, H. Korterink, H. Scholtens	
Principal(s)	Novem	

ECN project number 7.4172
Principal's order number 2020-01-13-10-005

Programme(s) DEN

Abstract

The large-scale implementation of wind energy is hampered to a large extent by the unknown effects that wind turbines may have on the environment. The collision of birds with turbines and the distortion of the migration routes are in that respect points of great concern. The project "*WT-Bird , A low cost solution for detecting bird collision"* focused on developing a reliable and cheaper method for counting bird collisions in order to obtain more insight in the actual size of the problem, especially in offshore applications for which no alternative detection method is available.

The report describes the work that has been performed to meet the objective "*developing and demonstrating a system that determines a bird collision against a wind turbine and with which it is possible to determine the bird species*". The system had to meet among others the following specifications:

- the system should be low cost in order to be competitive with manual counting methods;
- analysis of recorded data by e.g. ornithologist should not be labour intensive, meaning that only actual collisions should be recorded and no false data should be stored;
- the system should be able to operate under all weather and visibility conditions;
- the system should operate in offshore wind farms for long periods in a reliable manner and data should be accessible remotely.

The assembly of the prototypes has been carried out in this project successfully. They behaved robust and reliable during the field tests and only minor problems have been identified. Two major problems have not been solved completely in this project.

1. Triggering
   Birds can collide against rotors and towers in many different ways. The tests that have been performed with shooting tennis balls against the flat side of rotor blades and throwing sand bags against the tower did not cover the entire range of possible bird impacts. Secondly, the variety of possible microphone configurations and background noises for especially larger turbines is bigger than originally expected. The determination of a good algorithm for triggering should be further investigated. Within the constraints of the project, more detailed investigations were not feasible.
2. Image recording and recognition of bird species
   Already at an early stage in the project it was decided to use the Mobotix camera a.o. because it had a normal lens and a low-light lens, it could be accessed with commonly used web browser technology, and especially because it was cheap. During the field tests, the shortcomings of the camera became clear. The view during night-time was insufficiently clear for recognition of species. Additional light sources were necessary and the exposure time is too long, leading to too low sample frequencies. A large part of the project has been spent on improving the visibility during night-time but without being completely successful.

To solve these problems, further R&D work is recommended. More tests with dummies against larger turbines should be performed and the tests with cameras should be continued. Moreover, much more long-term field tests should be performed in close collaboration with ornithologists.

Key words Wind Turbines, Environmental Impact, Birds

Authorization	**Name**	**Signature**	**Date**
Checked	J.P. Verhoef		
Approved	L.W.M.M. Rademakers		
Authorized	H.J.M. Beurskens		