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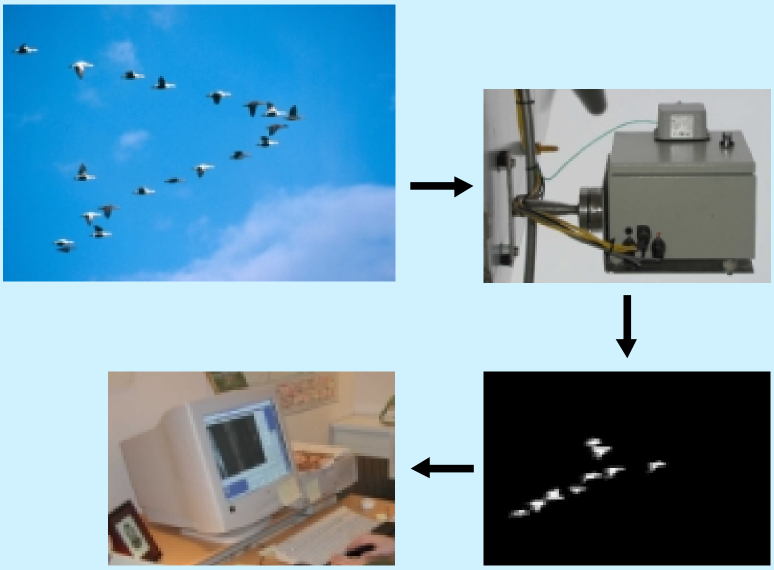
Thermal Animal Detection System (TADS)

Development of a method for estimating collision frequency of migrating birds at offshore wind turbines

NERI Technical Report, No. 440



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Mark Desholm

Data sheet

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Synopsis

This report presents data from equipment tests and software development for the Thermal Animal Detection System (TADS) development project: 'Development of a method for estimating collision frequency between migrating birds and offshore wind turbines'.

The technical tests were performed to investigate the performance of remote controlling, video file compression tool and physical stress of the thermal camera when operating outdoors and under the real time vibration conditions at a 2 MW turbine. Furthermore, experimental tests on birds were performed to describe the decreasing detectability with distance on free flying birds, the performance of the thermal camera during poor visibility, and finally, the performance of the thermal sensor software developed for securing high -quality data.

In general, it can be concluded that the thermal camera and its related hardware and software, the TADS, are capable of recording migrating birds approaching the rotating blades of a turbine, even under conditions with poor visibility. If the TADS is used in a vertical viewing scenario it would comply with the requirements for a set-up used for estimating the avian collision frequency at offshore wind turbines.

1 Introduction

The project 'Development of a method for estimating collision frequency between migrating birds and offshore wind turbines' arose from the need to develop a method capable of recording the number of avian collisions with Danish offshore wind turbines. Following an international work-shop on offshore wind farms and birds arranged by NERI at the Fuglsø Center, Denmark, in November 2001 (NERI in prep.), it has become clear that such a method to record collisions is also an urgent international requirement, as large offshore wind farms are planned to be erected in important marine bird areas in many European countries. Several studies have demonstrated that birds collide with wind turbines in terrestrial habitats (e.g. Pedersen & Poulsen 1991, Winkelman 1992), but conditions for monitoring impacts at sea are very different from those on land. Collisions are also likely to occur in offshore areas, although little information exists on this subject. Hence, methods for estimating the collision frequency at sea also have to be developed.

The following ideal characteristics were defined as prerequisites required of any method developed to estimate collision frequency of birds at offshore wind turbines:

- As previous studies have suggested that collision risk is highest at night and during periods of poor visibility (fog, rain or snow), the methods must be applicable under these conditions;
- as collisions most likely will occur as very low frequency discrete events, an automated system which can collect data in the absence of an operator is preferable and most cost effective;
- as different bird species will show different collisions frequencies, a method capable of discriminating between the species or groups of species is needed;
- as birds have been documented to be injured when caught in the wind turbulence vortices associated with the rotating blades, the method should be able to register these collisions also;
- as the study will be conducted offshore the system must be applicable in marine environments.

Out of several different methods considered for estimating collision frequency, remote thermographic monitoring, relying on a heat sensible video camera (hereafter referred to as the 'thermal camera'), complied most with the ideal requirements.

This final report presents the results obtained from equipment tests and software development for the Thermal Animal Detection System (TADS) project: 'Development of a method for estimating collision frequency between migrating birds and offshore wind turbines'. The project was financed by Elkraft System, PSO-F&U and was conducted in collaboration between SEAS Wind Energy Centre and National Environmental Research Institute (NERI), Department of Coastal Zone Ecology.

I would like to thank Henrik Quist from PræcisionsTeknik A/S for technical assistance and the people from ENERGI E2 A/S for their practical help in the installation process at the Rødbyhavn turbine. Finally, I thank Bonus Energy A/S for helping with the data transmission from Rødbyhavn to my office at NERI.

2 Methods

2.1 Thermography

All objects with a temperature above absolute zero, i.e. -273°C, radiate heat. Thermography is a method by use of which images of objects are obtained by measuring their own, and the reflected, heat radiation within the infrared spectrum of wave lengths of 2-15 m, and it contrasts the ordinary photographic images which result from the reflection of visible light (Fig. 1).

The thermal camera is positioned at some distance from the object, so the radiation passes through the atmosphere before reaching the camera. As the radiation is transmitted through the atmosphere, it is subject to a degree of attenuation due to particles, water vapour and mixture of gases in the air. Finally, the radiation reaches the thermal camera via a lens. The lens is made of germanium as IR-radiation is fully absorbed by glass. This is exemplified in Figure 1, which shows lower temperature of the glass in the sunglasses than of the surrounding face. The camera lens focuses the heat radiation onto the heat radiation sensors. These elements are called the infrared detectors and transform the received radiation into an electrical signal, which is then processed into a visible image, i.e. the thermogram.

2.2 Equipment

The thermal camera model chosen for this project is a Thermovision IRMV 320V from FLIR (Fig. 2), which has the following facilities:

- The spatial resolution of the camera is 320 x 240 pixels (76,800 detectors), and the colour of each pixel relates to a relative temperature value;
- it is based on the newest generation of detectors, which should provide the best resolution available;
- it is sensitive to radiation in the long wave (7-15 µm) infrared spectrum, which is less susceptible to absorption by the atmosphere than in the short wave (2-5 µm) spectrum;
- it is designed for industrial use, and hence, can be purchased at lower costs than comparable handheld models;
- it has no facilities for temperature measurement, which further reduces the costs, and at the same time meets our need for generating thermal images of birds, without measuring their exact temperature;
- it is fitted with a standard 24° lens, but also 12° and 7° telephoto lenses were used and tested. Specifications on the geometrical reso-

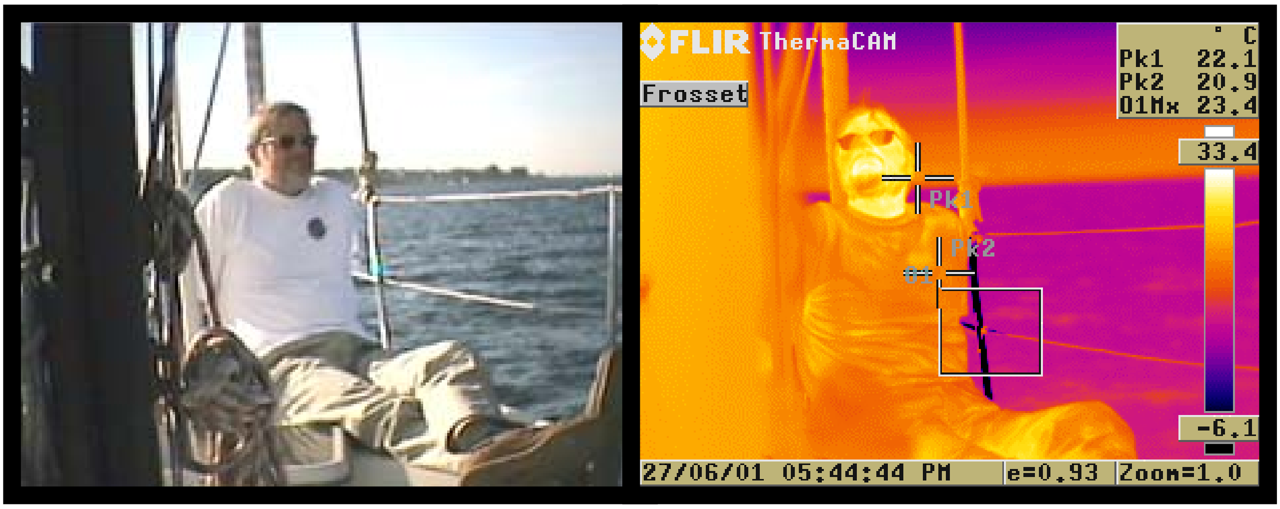

Figure 1. Photograph taken using equipment sensitive to visible light (left) and a thermogram using a heat sensitive camera (right) showing almost the same situation. The scale to the right on the thermogram shows the relationship between colours and temperatures.

Figure 2. Waterproof metal camera housing box with windscreen wiper (left) and the thermal camera inside (right).

lution and horizontal image size for the three lenses are given in Tables 1 and 2.

For more details on the camera model Thermovision IRMV 320V see specifications at the Internet site:

http://www.flirthermography.com/sweden/cameras/infrared_camera_complete/1004/.

The camera was installed in a waterproof metal box with remote-controlled windscreen wiper and sprinkler system (see Fig. 2), and the sprinkler liquid should contain at least 20% alcohol to prevent freezing. The box had a window penetrable by IR-radiation. The camera was mounted on the turbine with a specially designed mounting device made of steel (Fig. 3). This device made it possible to manually turn the field of view in different directions. To dampen the effects of the vibrations from the turbine, vibration absorbers made of rubber were fitted both between the box and the base plate of the mount, and between the mounting and the turbine (see Fig. 3).

The equipment must be lightning-shielded in order to secure the power installations within the turbine itself.

In the present study, the TADS was tested at a single land-based 2 MW turbine (Figs. 4 and 5). The thermal camera was mounted in a vertical position c. 4 m above ground level to create a vertical viewing scenario. In the tests, a 12º lens was used and it covered c. 25% of the sweeping area, defined as the two-dimensional area swept by the blades of the turbine (see Fig. 4).

At the turbine, a computer placed inside the turbine tower was connected directly to the thermal camera (Fig. 6). This computer was an 800 MHz Pentium 3 which is fast and powerful enough to handle, and temporarily, store large digital video files. The turbine computer was set to restart automatically after unintended power cuts, as manual restarts are rather expensive at offshore installations.

Within the present development project, thermal

Table 1. Horizontal image size (HIS; in metres) for the three types of lenses tested in the present project at distances of 10-5,000 metres between the lens and the object. HIS represents the distance dependent horizontal span of the field of view measured at a given distance from the camera in units of metres. * denotes the minimum distance between turbines at the Rødsand/Nysted wind farm.

HIS (m)	10 m	100 m	200 m	450 m*	500 m	1000 m	5000 m
7°	1.2	12.2	24.4	54.9	61.0	122.0	610.0
12°	2.1	21.0	42.0	94.5	105.0	210.0	1050.0
24°	4.2	42.0	84.0	189.0	210.0	420.0	2100.0

Table 2. Geometrical resolution (GR; in millimetres) for the three types of lenses tested in the present project at distances of 10-5,000 metres between the lens and the object. GR represents the distance dependent horizontal span of each pixel measured at a given distance from the camera in units of millimetres. * denotes the minimum distance between turbines at the Rødsand/Nysted wind farm.

GR (mm)	10 m	100 m	200 m	450 m*	500 m	1000 m	5000 m
7°	3.6	38.0	76.0	171.0	190.0	380.0	1900.0
12°	6.6	66.0	132.0	297.0	330.0	660.0	3300.0
24°	13.0	130.0	260.0	585.0	650.0	1300.0	6500.0

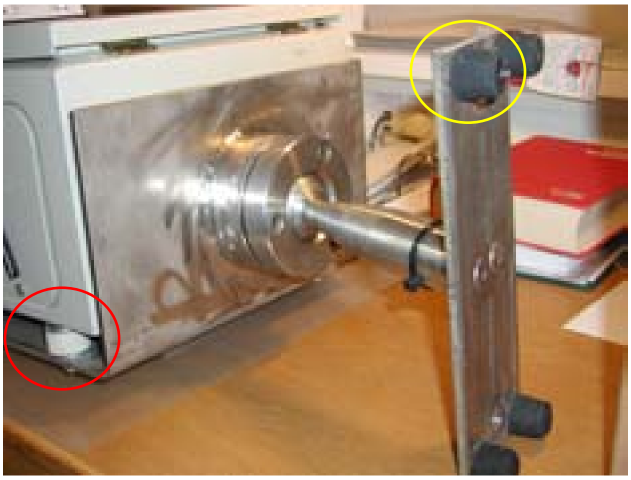

Figure 3. Camera mounting, showing the rubber anti-vibration devices placed both between the camera box itself and the mounting (red circle), and between the mounting and the turbine (yellow circle).

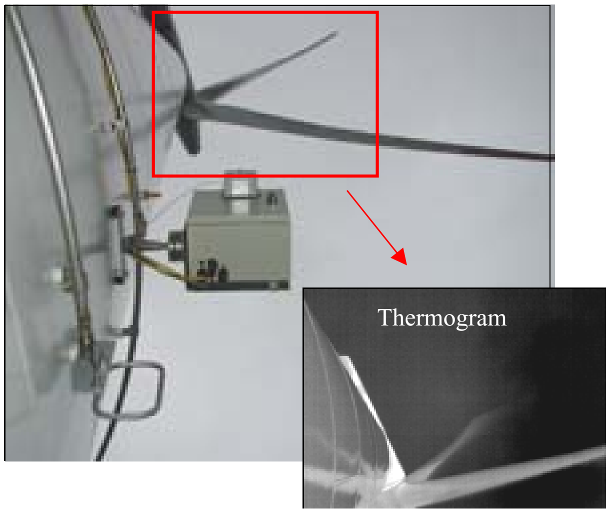

Figure 5. Vertical visual view from the base of the 2 MW testing turbine showing the mounted thermal camera and the resultant field of view as an inserted thermogram.

sensor software was developed which starts downloading video sequences to the harddisc when at least one pixel in the field of view exceeds an operator-defined threshold temperature level (Fig. 7). This ensured a minimum number of recording events so that only sequences of birds passing the field of view or colliding with the turbines were captured on the harddisc. Besides a minimum recording time facility, a maximum recording time facility was developed and built into the software (see Fig. 7). If the maximum recording time value is set at e.g. 6 seconds, long video sequences triggered by either the blades or nacelle due to shifting wind directions or caused by other relatively hot objects (e.g. clouds) could be prevented from occupying space on the harddisc.

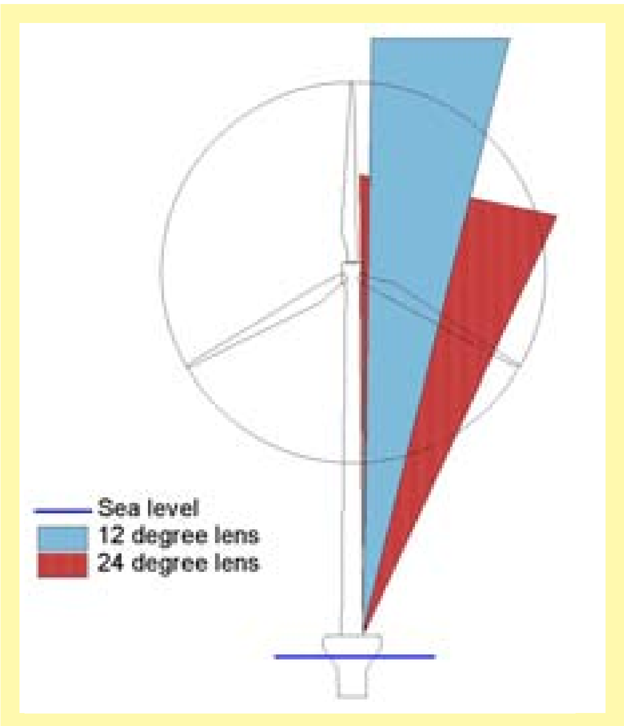

Figure 4. Schematic presentation of the vertical viewing scenario for eider ducks at a 2 MW turbine with a tower height of 70 m. The two different coloured areas depict the field of view of the 24° lens (red) and the 12° lens (blue). The 24° lens covers up to a maximum of 32.4% of the sweep area of the turbine blades, and the 12° lens a maximum of 25.3% of the sweep area, given the theoretical maximum observation distances for eider ducks shown in Figure 13.

Furthermore, operator-defined parts of the field of view can be excluded from the analysis performed by the thermal sensor software. In this way disturbing heat radiation from e.g. parts of a wind turbine can be eliminated, by simply masking off the part of the field of view in which the turbine is depicted. The mask is created in the software Paint (Fig. 8).

To make the data volume, in terms of bites stored, as small as possible an MJPEG-codec for compression of video files was applied. In addition, a framegrabber was installed which was programmed to grab and digitalise 25 frames per second from the analog camera signal. The software 'PC-anywhere' was used for remote control of the camera settings and for data transmission of video sequences between the turbine and the office at NERI. This software was also set to start automatically after power cuts, as connection can

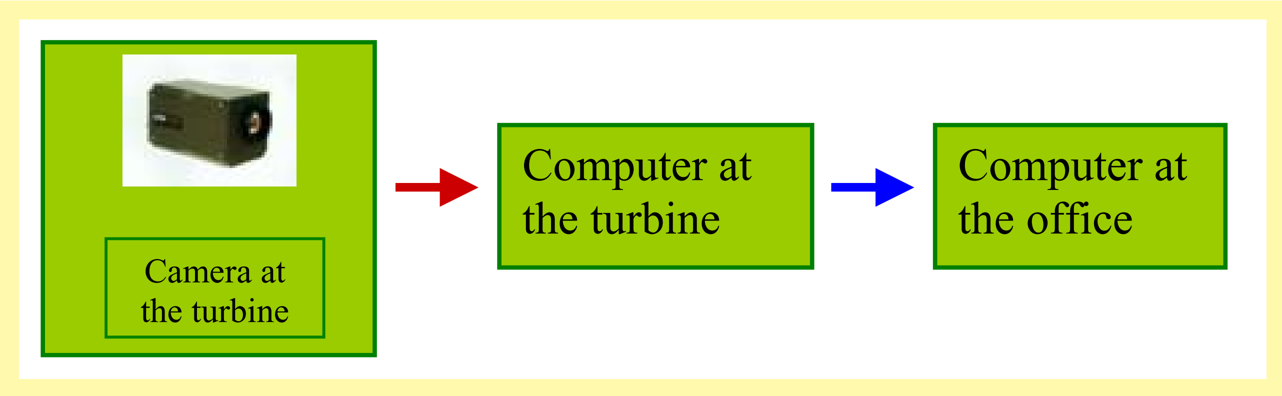

Figure 6. Schematic presentation of the thermal video set-up, including hardware (green boxes) and lines for data transmission (arrows). The red arrow represents the cable between the camera and the computer at the turbine tower, the blue arrow represents the optical fibres between the offshore wind farm and land and the ordinary telecom network to the final destination in the office at NERI.

only be achieved if the remote control software is running.

The base computer in the turbine is remote controlled from the computer at the NERI office, where a monitor, directly networked onto the internet, decompression software, software for viewing video sequencies and a CD-recorder for data storage were available. The connection from the NERI office to the turbine computer was es-

Figure 7. Interface of the software used for IR-video recording.

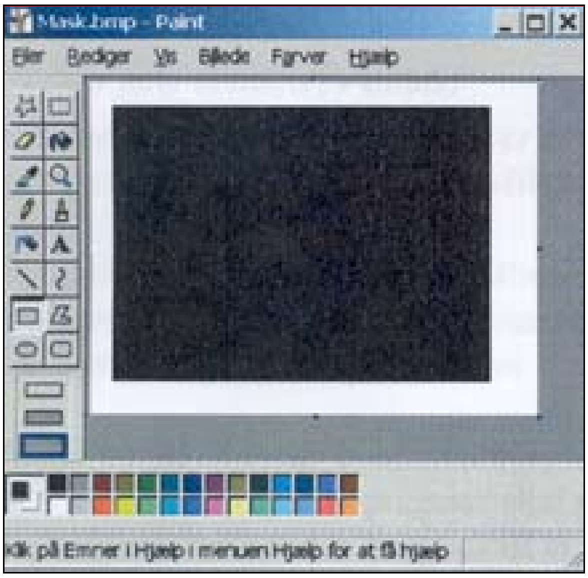

Figure 8. Interface of the software Paint. An imported bitmap-file of the field of view of the thermal camera can be used to mask disturbing hot objects. Here a black mask has been created so that only the outer part of the field of view (the white part) is used for determining the maximum pixel value.

tablished by first logging on at the local network of the operator company of the turbines via a VPN-Client and thereafter the remote control software searched for and found the specified IP-address.

2.3 Tests

Three test sites were used:

1) Gedser Odde in the southern part of Denmark for tests on free flying common eider *Somateria mollissima* (hereafter referred to as eider duck) and other bird species,
2) Kalø in eastern Jutland for testing the equipment in situations of bad visibility using a captive chicken and pheasant,
3) Rødbyhavn for tests at a 2 MW turbine using the vertical viewing scenario.

2.3.1 Technical tests

The following tests of the hardware and software were performed:

- A test of the performance of the remote control software 'PC-anywhere', using the internet connection between the turbine and the office at NERI. The main questions to be answered were: 'what is the time delay between the click at the computer mouse and the responding action?' and 'is the time delay too long to be operational?'. The time delay was estimated using a wristwatch with a second hand, and the criterion for being operational was fully subjective;
- a test of the 'MJPEG codec' to investigate the relationship between the compression factor and the file size. The main question to be answered was: 'which compression factor gives the best combination of file size and image quality?'. Eleven sequences using different compression factors were recorded to show the relationship between file size and compression factor. File size was measured as Kb/second, and plotted against the used compression factors. The subjective criterion for image quality was set to be as good as the quality of non-compressed sequences, as no reduction in quality can be tolerated if single individuals within bird flocks should be distinguished from each other;
- a test of the physical stress of the thermal camera when operating outdoors and under the real time vibration conditions at the 2 MW turbine at Rødbyhavn. This test was conducted to see how well the waterproof metal box, windscreen wiper, sprinkler system and rubber vibration absorbers worked. The criterion for success was a well working set-up during the testing period, which showed no reduced image quality due to environmental impacts.

2.3.2 Experimental tests on birds

On birds the following tests were performed:

- Tests with a 12° lens and a 7° lens were performed at Gedser Odde to describe the decreasing detectability with distance on free flying eider ducks. The distance between the camera and the eiders was measured using a laser range finder with an accuracy of ±5 m. The length of a bird (the part of the silhouette, which contrasted to the black background) was measured in units of pixels at one frame from a video sequence.
  In order to evaluate the usefulness of other

lenses which were not tested in the present study, the theoretical body length to distance relationships for eider ducks was generated. The lens specific mean geometrical resolutions (MG) normalised with regard to distance were calculated for each lens by use of the formula:

$$MG = GR/D \qquad (1)$$

where GR = geometrical resolution (in mm) and D = distance (in m) between the camera and the object (see Table 2).
A theoretical body length, b, of 400 mm for an eider duck was applied and the theoretical monitor body length, B, in the unit of pixels was computed using the following equation:

$$B = \frac{b}{D \times MG} \qquad (2).$$

- Tests of the equipment during nocturnal conditions and in situations of poor visibility. One of the key demands placed upon the set-up, is its ability to operate under the conditions when most collisions are expected to occur. The heat radiation pattern during nocturnal circumstances does not differ from that of day-light situations, and hence, the present study concentrates on documenting the performance of the thermal camera in situations of poor visibility during day light. A caged chicken (Fig. 9) was used for controlled visibility tests during severe snowfall and a caged pheasant (Fig. 10) during severe fog, both of which had the same body length of c. 300 mm (tail excluded). Both were tested against a control in conditions of good visibility. The visibility tests were performed along small gravel roads where small stakes were set out at 25 m intervals. In this way a single test operator could easily determine the distance between the camera and the caged bird at any given level of visibility. The camera was started and the bird was moved along the road. At each 25 m, a signal was given so the single frames generated at each distance interval could be determined later on in the office during further analysis;
- Tests of the performance of the thermal sensor software, regarding its ability to detect and trigger on the basis of flying birds. The tests were conducted on free flying waterbirds migrating over the sea at Gedser Odde. The questions to be answered were: 1) could the software trigger fast enough to capture the main track of a bird passing the field of view? and 2)

Figure 9. Caged chicken used for the visibility tests during a severe snowstorm.

Figure 10. Caged pheasant used for the visibility tests during heavy fog.

which background elements were the best to most effectively trigger the thermal-recordings?

2.3.3 Estimating the number of collisions

It is well known that birds collide with land-based wind turbines (Pedersen & Poulsen 1991, Winkelman 1992), and infrared cameras are one method, which can be used in estimating the collisions frequency at offshore wind turbines. However, due to the high number of relatively large turbines, a monitoring scheme aiming at covering an entire wind farm with respect to avian collisions, may not be operational from an economic point of view. Hence, a modelling approach may be needed, using species specific migration models that describe the spatial and temporal presence of migrating birds in the wind farm area. When it is known where and when the different bird species are migrating within the wind farm area, some estimates are needed of the species specific probability of collision. Combining the migration models, describing the volume of birds migrating, and the species specific collision frequencies, enables the researcher to estimate the number of birds that may collide with turbines at a given wind farm.

2.4 Quality control

All data were derived from recorded video sequences and stored in databases. Unusual data were tagged and commented to enable a later exclusion of erroneous data. After having stored data in databases, the original data were checked once again.

The following quality control procedures were imposed throughout the production of this report:

- Internal scientific review by a senior researcher
- Internal editorial and linguistic revision
- Internal proof-reading
- Layout followed by proof-reading
- Approval by project managers.

3 Results

3.1 Technical tests

The delay of the remote control was at all times less than three seconds, and thereby it had no influence on the practical use of the software. The transmission of video files occurred at speeds of c. 20 Kb/second (range: 17-23Kb/second).

Uncompressed video files consist of 2000 Kb/second, whereas even a minimum of compression with the 'PICVideo MJPEG'-codec (factor 18) reduces the size by nearly 90% (Fig. 11). At compression factors below 15, the resolution of the image is severely decreased, resulting in an image not suitable for detecting single flying birds within a flock.

No negative effects from vibrations of the turbine were detected on the recorded video sequences, and this holds at least for wind speeds of up to 9 m/second. The 20% alcohol sprinkler solution proved effective under frosty conditions (-10ºC). The waterproof box was heated inside by the power supply of the camera, and because the ambient temperature was between -5°C and +10°C condensed water accumulated within the box during the trial, and after c. one month of operation 1-2 dl of water had accumulated.

3.2 Experimental tests on birds

It turned out that the minimum distinguishable length of a single flying eider duck, measured at the monitor in units of pixels, should be c. five pixels if individual eider ducks were to be distinguished within larger flocks by the operator of the camera. It should be noted, however, that species identification using these minimum distinguishable lengths will be based on flock structure and flight speed only, since five pixels are insufficient to discern species/group specific silhouettes which requires 10-15 pixels of length. Given the minimum distinguishable length of five pixels, the maximum operation distances for the 12° lens lie somewhere between 130 and 170 m for eider ducks (Fig. 12), and for the 7° lens between 260 and 400 m (see Fig. 12).

The theoretical values calculated for eider ducks (Fig. 13) tend to be displaced towards smaller body lengths, for a given distance, compared to the empirical values for the same types of lenses (see Fig. 12).

The focus species of this study is the eider duck, and hence, only limited data on other species are available. However, the 12° lens can record even

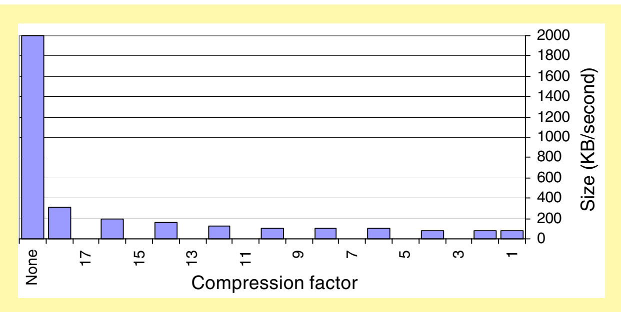

Figure 11. File size (in KB/second) as a function of compression factors 1-19. A high factor represents a low compression and hence a relatively high quality of the IR-sequence. 'None' denotes the uncompressed situation.

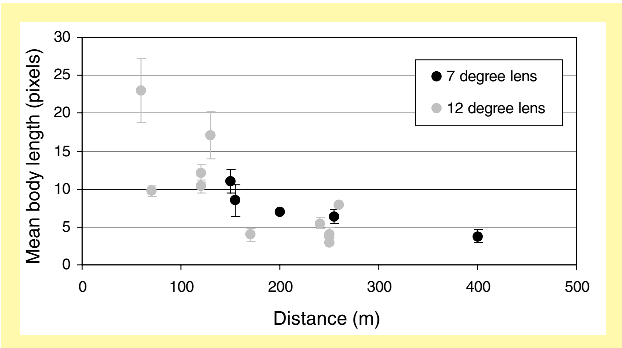

Figure 12. Relationship between the mean body length of the flying eider ducks (in number of pixels ± SD) and the observation distance (in metres). Data were collected with a 7° and 12° lens, respectively.

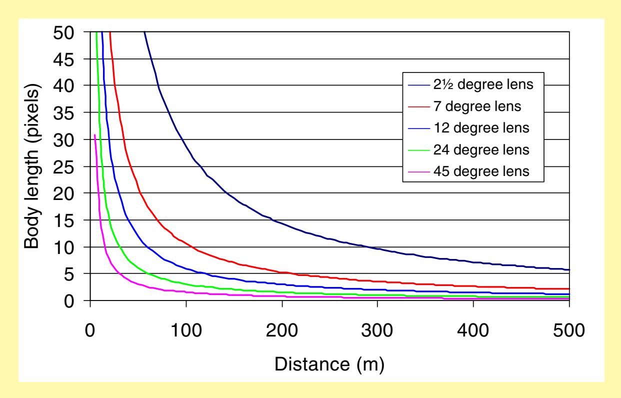

Figure 13. Theoretical relationship between the body length of a standard eider duck (in number of pixels) and the observation distance (in metres) for five different types of lenses. Input data were calculated according to Equation 1 and 2.

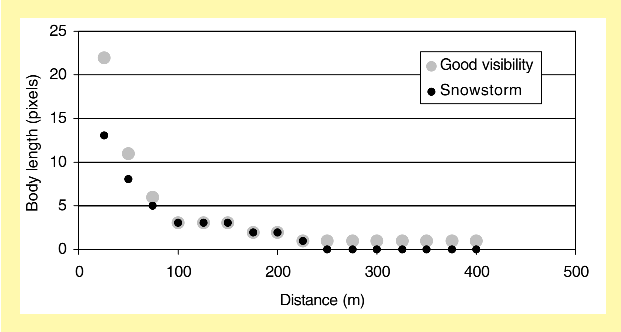

Figure 15. Relationship between body length of the caged chicken (in number of pixels) and the observation distance (in metres) during good visibility on a sunny day and during a snowstorm. Data were collected using a 12° lens.

small passerines (meadow pipit *Anthus pratensis*, starling *Sturnus vulgaris* and pied wagtail *Motacilla alba*) when they are within a relatively short distances (<50 m) of the camera (Fig. 14).

On 19 February 2002 a heavy snowstorm passed Denmark resulting in a visibility of approximately 30 m at the test site. During this period, tests on the caged chicken were conducted with the 12° lens. At distances beyond 225 m, the chicken disappeared from the monitor (Fig. 15). In the control tests in good visibility the chicken could be seen as a single pixel to at least 400 m. At distances of up to 225 m the performance of the camera was nearly as good in the snow storm conditions as in the control situations a few days later when the weather was sunny with a clear sky. Within a distance of 100 m, the measured body length tended to be smaller during the snowfall than in the clear sky condition.

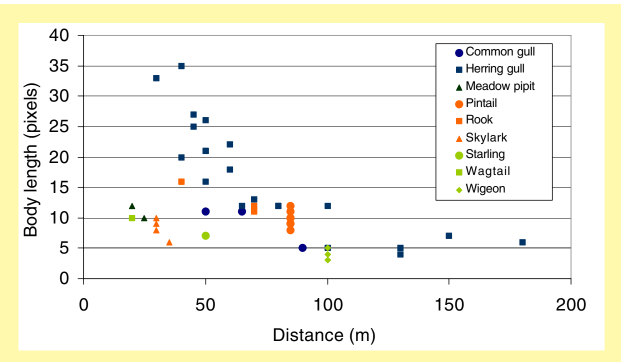

Figure 14. Relationship between the body length (in number of pixels) of nine bird species recorded in flight and the observation distance (in metres). Data were collected using a 12° lens.

On 3 October 2002 the visibility at the test site was c. 30 m due to fog, and the pheasant was used to investigate the performance of the thermal camera and the 12° lens under foggy conditions. At distances beyond 70 m, the pheasant disappeared from the monitor (Fig. 16). In the control tests made in light fog and no fog conditions, the pheasant could be seen to a distance of at least 175 m.

The software triggered extremely fast and therefore proved effective in securing recordings of birds passing the field of view. In Figure 17, different bird species entering the field of view from the right are depicted. As the sensor software can start downloading on the basis of only one pixel, it works well also on small passerines as can be seen from Figure 17.

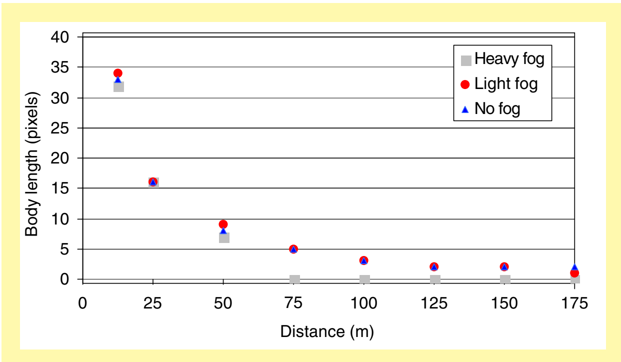

Figure 16. Relationship between the body length of the caged pheasant (in number of pixels) and the observation distance (in metres) in three different situations: heavy fog (visibility = c. 30 m), light fog (visual visibility = c. 200 m), no fog (visual visibility > 1000 m). Data were collected using a 12° lens.

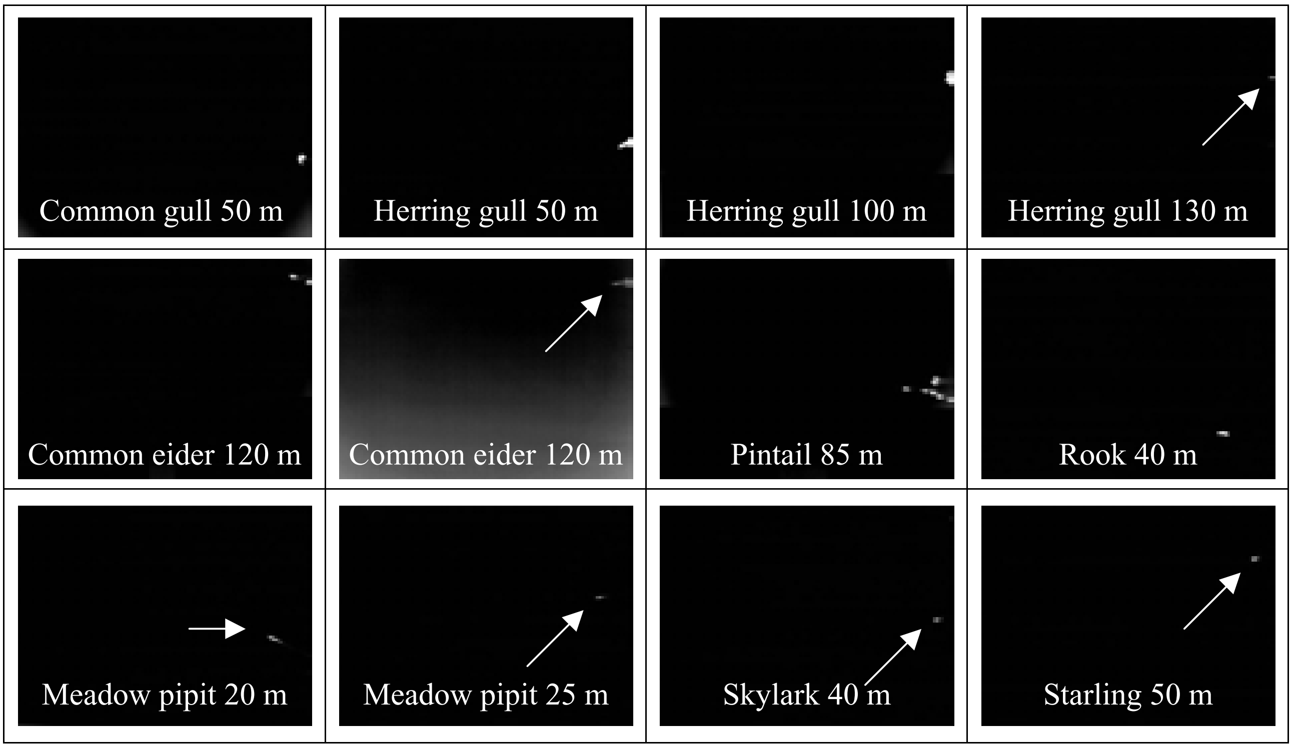

Figure 17. First frame of several thermographic video sequences of eight bird species entering the field of view from the right at different distances, and triggered by the thermal sensor software. Data were collected using a 12° lens.

The performance of the thermal sensor software was also investigated using different backgrounds. It turned out that the background must be uniform in terms of temperature pattern if the software is to perform well. The use of the sea surface as background turned out to be impossible, as it reflected infrared radiation from both the very hot sun and very cold space in a very complex and continuously changing dynamic temperature pattern (Fig. 18). When using the sea surface as a background, the thermal sensor software triggered recordings continuously. In contrast, the software performed as effeciently as intended with the sky as background, either a fully clouded or clear sky, as both exhibit uniform temperature patterns. With such a uniform background the thermal sensor software was easily set to trigger when birds were passing. In situations where the sky was partially clouded, the drifting clouds tended to trigger the thermal sensor software.

Figure 18. Thermal view of the sky, the horizon and reflections at the sea.

4 Discussion and conclusions

4.1 Technical tests

Data transmission between the thermal camera at the 2 MW turbine at Rødbyhavn and the office at NERI was successfully tested. The described size(s) of 200 Kb/second of the compressed video sequences and the data transmission rate (r) of 20 Kb/second, give a transmission time (t = s/r) of compressed video files of c. 10 times (10 = 200 Kb·second^{-1} /20 Kb·second^{-1}) the length of each sequence. Since the quality of compressed files, down to compression factor 15, is the same as the uncompressed files it is suggested to use a compression factor of 15-18 when birds are the thermal subjects. The time delay of a maximum of three seconds during remote controlling constituted no practical problem.

Water condensing within the metal box was recognised as a potential problem during the outdoor testing phase, but this problem can be solved by applying a small water valve in the bottom of the environmental metal box to permit draining. As a further supplement to the water valve, water-absorbing silica crystals could be used.

Vibrations from the 2 MW turbine had no influence on the recorded video sequences during the testing phase, and even higher wind speeds are not expected to decrease the quality of the thermal recordings, as higher wind speeds do not alter significantly the speed of the blades due to the turbine gear system. On this basis, the rubber vibration absorbers are concluded to have fulfilled their purpose, at least at wind speeds up to 9 m/second.

4.2 Experimental tests on birds

The displacement of the theoretical graphs (Fig. 13) compared to the empirical graphs (Fig. 12) towards smaller body lengths for a given distance, can be explained by the relatively fast flight speeds of the eider ducks (c. 80 km/hour). A flying bird will be depicted as a stretched-out silhouette, and hence appears longer, if the bird is flying longer than the length represented by one pixel at a given distance during the time it takes to shoot one frame (shutter speed = 1/50 seconds).

On average, the theoretical body lengths (Fig. 13) turned out to be just c. 60% of the field values (Fig. 12) at the same distances, and hence, a minimum distinguishable body length of only three pixels (5 x 0.60) should be used when estimating the theoretical distances at which the different non-tested lenses can detect single flying eider ducks.

Bird collisions at offshore wind farms are expected to occur most often during periods of poor visibility. Hence, the performance of the TADS during these situations is crucial for its suitability as a method to register bird/turbine collisions. Birds could be detected by the thermal camera at a distance c. 3 times longer during severe snowfall (225 m) than in dense fog (70 m), compared to visual detection of c. 30 m in both cases. This discrepancy in the thermal detectability could potentially have arisen because the pheasant might have become wet from the moisture of the fog, and therefore might have become cooler due to the evaporation process. As a result, the water droplets in the air and the pheasant may have obtained more or less the same temperature characteristics and therefore were rather difficult to distinguish from each other. In contrast, the chicken was exposed to frozen snowflakes, which were blown off the feathers by the wind, and therefore it may have remained dry and relatively warm. As the temperature difference between a dry bird (20°C) and frozen snowflakes (c. -1°C) is 200 times higher than the sensitivity of the thermal camera, a clear image was easy to obtain. It is likely that the performance of the TADS during heavy fog could be improved by lowering the temperature span of detection of the thermal camera significantly. By doing this, setting the right temperature level for the thermal camera becomes difficult. The more experience the operator obtains in the camera settings during foggy conditions, the better performance will be achieved. For the meantime, an operating distance of 70 m during heavy fog should be viewed as an operational minimum distance for medium-sized bird species.

The thermal sensor software, which has been developed specifically for this project, has performed according to the specification. The recordings are triggered extremely fast, but the performance is limited to situations with either a clear or fully clouded sky. If clouds are drifting at a clear sky, they may trigger the recording due to their relatively high temperature of c. 10°C compared to a background temperature of c. -40°C from space. Similar limitations were reported from a thermography study on migrating birds at Falsterbo in Sweden where a vertical viewing scenario was applied also (Zehnder et al. 2001). In general, the thermal sensor software seems to be a robust tool to ensure that only thermographic video sequences with birds passing the field of view are stored on the harddisc.

4.3 Conclusions

Under the present proposals for construction of the planned offshore wind farms, turbines will be at least 110 m high and will be placed more than 450 m apart. Based on the results from the thermal imaging equipment presented in this report, it was only possible to distinguish birds from images with minimum body lengths of 3 and 5 pixels (see Figs. 12 and 13). On this basis, and given the planned size and distance between the turbines, it is concluded that only the 2½° lens, which was not tested in the study, would be able to operate satisfactorily in the horizontal viewing scenario (thermal camera at one turbine monitoring the neighbour turbine). In the vertical viewing scenario (thermal camera at the base of a turbine monitoring the sweeping area of the same turbine), with an operational distance of 110 m, the 12° and 24° lenses (which are cheaper) can be used.

In considering choice of scenario to be used, the following arguments pros and cons can be adduced:

- The thermographic visibility was restricted during trials undertaken in heavy fog to c. 70 m, at which data collection can still continue using the vertical viewing scenario.
- Species/group identification will be greatly enhanced over the shorter distances involved with vertical mounting of the thermal camera, since the long distances involved in horizontal mounting will increase radiation attenuation and reduce the amount of additional information available (e.g. bird shape, behaviour, wing-beat frequency).
- The recordings of smaller passerine bird species will be much more detailed and numerous due to the reduction in distance, and hence, the reduced degree of attenuation at the vertical viewing scenario.
- The horizontal image size using a 2.5° lens will be restricted to only 19.6 m at the distance of 450 m (24.5% of the sweeping area), and hence, two cameras will be needed to obtain the same coverage (32%) as achieved in the vertical scenario with the 24° lens.

Erection of a separate recording platform at the lens specific optimal distance from the turbine of interest could make the horizontal scenario applicable. However, the erection of such a platform with the necessary optic fibre connection to the general wind farm network would be prohibitively costly compared to a mounting associated with the planned existing infrastructure.

From this it is concluded that the vertical scenario will provide the best information.

If the vertical scenario is used, the amount of data could be increased significantly if the mounting device could be rotated in different directions by the operator remotely from the office, or more sophisticated, could follow the changes in direction of the nacelle automatically, and hence the blades, during periods with changing wind directions. At present, the method is restricted to monitoring the periods during which the blades are directly above the fixed point where the thermal camera is mounted. If the camera could somehow follow the turbine blades as the wind changes, data could be collected at all stages irrespective of wind direction.

In general, it can be concluded that the thermal camera and its related hardware and software, the TADS, are capable of recording migrating birds approaching the rotating blades of a turbine, even under conditions with poor visibility. If the TADS is used in a vertical viewing scenario it would comply with the requirements for a set-up used for estimating the avian collision frequency at offshore wind turbines. The present report describes the TADS in the context of monitoring avian collisions with static wind turbines only, but the set-up is likely to perform just as well on other animals, as long as the surface temperature is different from the temperature of the surrounding habitat.

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