

Review of methods and techniques for field validation of collision rates and avoidance amongst birds and bats at offshore wind turbines



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Review collision detection and flux measurements, birds and bats at offshore wind turbines

1 Introduction

The Dutch government has started a new round of wind energy development in its EEZ. The aim is set at 4500 MW in 2023. Directly related to these developments, a research programme on ecological effects has been designed, building on research and monitoring carried out in The Netherlands and abroad. The programme, called 'Wozep' (Wind op Zee Ecologisch Programma) will run until 2021. In 2016 some initial steps have been taken.

One of the aims in Wozep is to design an integrated monitoring programme, aiming at detecting collisions of birds and bats, and simultaneously carry out measurements of species-specific fluxes of both groups. This should be done around the wind farm, within the wind farm and in the rotor-swept area (RSA). This way, the programme should result in species-specific collision risk figures. The results of such a monitoring programme will also be used to improve collision risk modelling (e.g. the Band Model - Band 2000, 2012, Band *et al.* 2007, Masden 2015, Masden & Cook 2015 - or the Flux Collision Model, Kleyheeg-Hartman *et al.* in prep.).

One of the tasks to be completed in 2016 is an inventory and review of systems and techniques that can be used to carry out the measurements described above. This will eventually lead to a draft TOR (Terms of Reference) for a field project. This report provides the inventory and review only.

The aim of this report is to provide a full overview of 'state of art' monitoring systems and methods that are currently available and/or in development, and can be used as (part of) an integrated monitoring programme to measure collision victims and fluxes of birds and/or bats in offshore wind farms. The review will deal with relevant features of the systems: effectively measure collisions in combination with fluxes (within reach of wind farm, within wind farm and in Rotor Swept Area - RSA), species specificity of both, data-processing (real time vs indirect), applicability in different weather and light circumstances (night time), requirements related to installation, network band width, power supply etc.

The review is meant to give a general overview of what is available to carry out the measurements Rijkswaterstaat may decide to include in Wozep. It is aiming at showing there is a variety of solutions available, not a detailed comparison aiming at a ranking or quality comparison. Also, this is a snapshot: data on systems will be different tomorrow. Anyone interested in using any of the systems will have to compare the actual capabilities of systems, and features not (yet) evaluated in public papers or reports will have to be shown or demonstrated by system producers.

2 Methods

2.1 General

The search is for methods and techniques for two types of measurements: detection of collisions and (continuous) measurements of fluxes at different spatial scales. These two types have to be available for both birds and bats. So, we have four categories: collision detection of birds, collision detection of bats, measurements of flux (MTR) of birds, and measurements of flux (MTR) of bats.

Depending on systems/methods/techniques, combinations may be possible (e.g. detect collisions of birds and bats with same system, measurements of flux in RSA with detection of collisions). However, these four categories will be treated separately to start with. When reviewing, the pros and cons of combinations will be evaluated (chapter 5).

In the inventory the word 'system' will be used for any combination of methods, techniques, systems etc. that is available to do one of the measurements defined above.

Systems have been 'found' by using earlier reviews, research field knowledge and checking with some colleagues. Although several reports providing overviews have been written, the most useful were two reports that were the result of the Crown Estate 'SOSS'-project in the UK (Collier *et al.* 2011, 2012).

2.2 Fact sheets

For each of the systems the knowledge needed and available is put together in a 'fact sheet'. For these a more or less fixed format was used, but in some cases headings were omitted or added as this seemed appropriate. After a general description and a status description, characteristics of the system, technical specifications, background information and reference projects are described. If available, information on practicalities important for deployment and costs, is included.

The information was obtained from reports, papers and websites. In some cases personal communication was a useful addition to written information. In some cases, the author had had personal contact longer ago and information was updated from written sources. All fact sheets were sent to the owner/producer of systems, asking for comments and/or additions. However, the final version is the responsibility of the author of the report.

3 Inventory

3.1 Detection of bird collisions

The inventory yielded the following systems that potentially detect collisions of birds at wind turbines, and might be deployed offshore. These systems are in different stages of development, which will be addressed in the respective fact sheets.

- WT-Bird: ECN, The Netherlands
- TADS (Thermal Animal Detection System), now part of Carbon Trust ORJIP systems, NIRAS-DHI, UK¹
- VARS (Visual Automatic Recording System): IfAOe, Germany
- DT-Bird: Liquen Consultoría Ambiental S.L., Spain
- ID-Stat: Calidris, France
- ATOM (Acoustic and Thermographic Offshore Monitoring): Normandean Associates Inc., USA
- ACAMS (Aerofauna Collision Avoidance Monitoring System): Biodiversity Research Institute/HiDef, USA
- Wind Turbine Sensor Unit for Monitoring of Avian & Bat Collisions: Oregon State University, USA

3.2 Detection of bat collisions

Bat fatalities at wind turbines are often not caused by direct collision, but by so-called 'barotrauma': the large differences in air pressure around the turbine, close to the blades, cause fatal internal trauma. Therefore, detection systems based on detecting objects hitting the blades and/or tower cannot be used for detection of bat collisions. That leaves the options of camera-based systems.

So far, no specific bat collision detection system is operational. Some of the bird collision detection systems can detect bat fatalities as well: TADS, VARS, ATOM, ACAMS. Also, two very recent developments by Oregon State University (USA) and Wageningen Marine Research (NL) specifically aim at (also) detecting bat fatalities.

3.3 Measurements of bird fluxes (MTR - Mean Traffic Rate²)

Bird fluxes can be measured in many ways. In this case, the flux has to be measured continuously, at an offshore site, and at different spatial scales. This limits the number of options available. Roughly, there is a choice between radar-based systems and camera-based systems.

Bird radar

Several types and makes of bird radar can be deployed offshore as they are fully automated and accessible through a network link. Systems to be described here have been selected because they have been applied successfully in similar offshore projects:

- 3DFlex radar: Robin Radar, Netherlands
- Merlin Bird and Bat Radar: DeTect Inc., USA
- BirdScan MR1: Swiss Birdradar, Switzerland
- Birdtrack: Strix (Portugal)
- DHI Bird Detection System with Scanter 5000 Radar: Terma & DHI (Denmark)
- DHI Bird Detection System with LAWR 25: DHI (Denmark)

The latter two are part of the UK ORJIP project, but also in use apart from that.

Other types of radar are available that may provide the same quality of data and services but have (as far as could be found) not been applied offshore (e.g. Accipiter Radar, Canada).

¹ Information on the results of the Carbon Trust ORJIP project is confidential until approx. summer 2017. Texts in this report have been submitted to and approved by the Carbon Trust.

² MTR, Mean Traffic Rate, is the number of birds passing a fixed line of distance over a set period - normally 1 km and 1 hour, regardless of flight altitude.

Bird radar types that are not operating independently from observers/operators have not been taken into account, as they cannot be operated 24/7 at offshore sites. In general, these are systems needing a human operator to store data in some way, and/or with video-grabbing software (sometimes even to be started manually) providing lower quality data. These are good for use in short-term field research on land, but not for 24/7-operation offshore.

In general, bird radar systems contain more hardware to be attached to the offshore constructions than camera systems. Vertically directed radars may interfere with rotor blades when placed directly underneath, at the wind turbine tower.

Especially horizontally oriented radars may have problems detecting birds because of radar clutter originating from waves. Of course, manufacturers have tried to tackle this, and some systems have been modified to this end. Some are more successful than others, but this may be hard to get quantified.

Camera-based systems

Basically there is a wide range of options for the use of cameras. However, for our purpose and with the demands of 24/7 operation offshore, only systems where cameras are integrated with software and technically protected to offshore conditions have been reviewed. Systems that have proven to be applicable offshore are limited in number and there is a big overlap with the systems mentioned in § 3.1:

- VARS (Visual Automatic Recording System): IfAOe, Germany
- DT-Bird: Liquen Consultoría Ambiental S.L., Spain
- ATOM (Acoustic and Thermographic Offshore Monitoring): Normandeu Associates Inc., USA
- ACAMS (Aerofauna Collision Avoidance Monitoring System): Biodiversity Research Institute/HiDef, USA
- • TADS (Thermal Animal Detection System), now part of Carbon Trust ORJIP systems, NIRAS-DHI, UK³
- WT-Bird: ECN, The Netherlands (has cameras as part of system, whether these can be used for this purpose will be discussed)

3.4 Measurements of bat fluxes (MTR - Mean Traffic Rate)

So far, bat fluxes have not been measured in the way this project asks for. Common practice is the use of 'bat detection', which gives time and frequency bats are close to the recorder. From these data it is impossible to extract numbers of bats or fluxes, as the sound detection is not directly related to numbers of individuals or even numbers of flight movements. Only relative abundance can be extracted - and even this may be affected by behavioural differences over time. Also, the distance over which bats can be observed this way is lower than 100 m.

Radar can be used to track bats. Some of the bird radar systems track bats, this will be mentioned in the fact sheets and discussed in chapter 5.

Camera-based systems: see § 3.3. These could be combined with bat-detection for selection of footage to be analysed. This will be mentioned in fact sheets where appropriate and discussed in chapter 5.

³ Information on the results of the Carbon Trust ORJIP project is confidential until approx. summer 2017. Texts in this report have been submitted to and approved by the Carbon Trust.

4 Fact sheets

Factsheet WT-Bird

owner/producer: ECN (Petten, The Netherlands)

general description

WT-Bird was developed at the Energy research Centre of the Netherlands (ECN) over 10 years ago. WT-Bird uses a combination of accelerometers and microphones to detect collision incidents, and video cameras to record video footage of the event (Figure 1) (Wiggelinkhuizen *et al.* 2004, 2006a, 2006b).

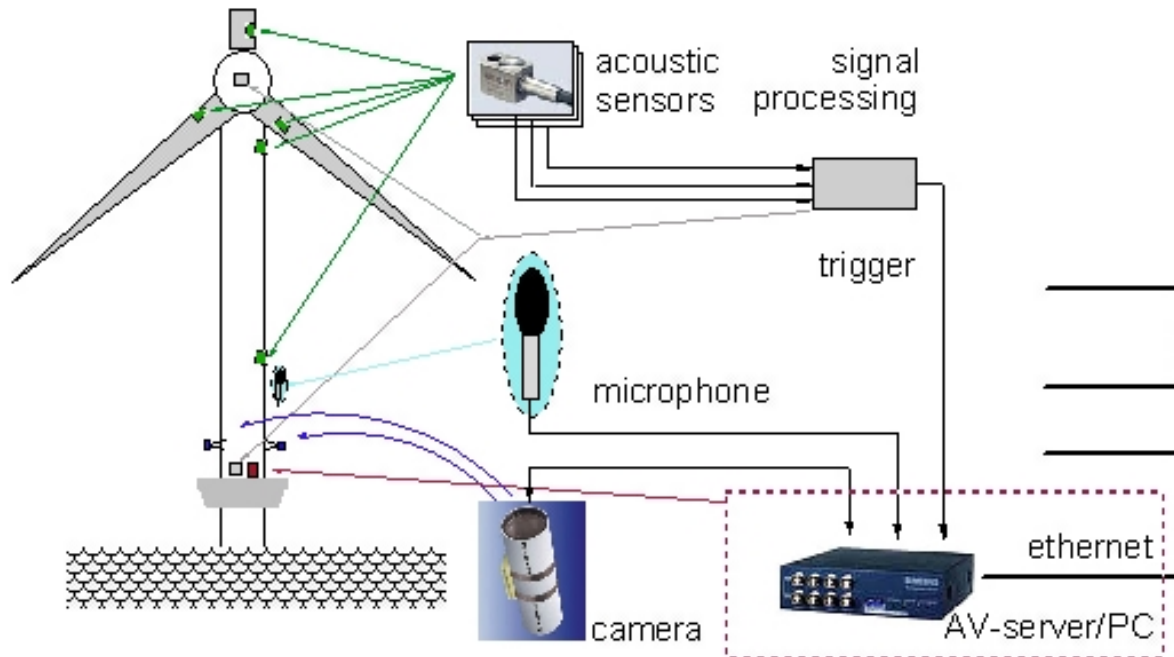


Figure 1. WT-Bird schematic overview (from Wiggelinkhuizen *et al.* 2006b). Since then, changes have been made, e.g. 2 sensors in each blade.

status

WT-Bird has a long history, in which development and testing have been combined in many cases. See the series of references given below. In summary: proof of concept has been successful, onshore tests and onshore operation successful (with Nordex turbines). More recently, offshore tests (with Vestas turbines) have been successful. Currently one system has been in operation at Offshore Wind farm Egmond aan Zee (OWEZ, NL) for a number of years. Cameras were added to this system in spring 2016 and measurements are ongoing.

characteristics in detail

The sensors detecting the collisions are situated in each of the rotor blades and in the tower. The signal is analysed real-time by software to filter out background and operational noise. The software can be adjusted to account for use on different turbine types and under various weather conditions, such as rain. Cameras are installed at the base of the tower looking up, in such a way that the rotor blades are always entirely in view.

When the sensors detect a signal and WT-Bird classifies this as a potential bird collision, the system stores video footage from before and after the time of the trigger. This is now set at 30 sec before and 30 sec after, but this time window can be defined by the user.

Sound and images are stored and sent to the user, through whatever connection is available.

The sensors are limited in detection. The signal of a bird hit has to be detected by the sensor and filtered out from the background noise by the algorithms. This results in collisions of smaller birds staying undetected. ECN does not exactly know where the size limit is, but it is likely that collisions of most songbirds will not be detected. Whether starling/thrush size songbirds can be detected is not sure yet. As birds can hit the turbine differently, it will not be a clear limitation in bird size: larger birds may touch the turbine 'softly' and stay undetected as well, smaller birds may hit 'upfront' and be detected.

technical specifications

Details on technical specifications are available in reports cited at the end of this fact sheet. Recently there are developments in hardware for data handling in the tower, which is now in line with ECN's standard for instrumentation. Cameras available on the market are of course continuously improving. ECN is currently reviewing which cameras show best performance for the purpose. In fact, for every new development state-of-the-art cameras are chosen. Thermal imaging cameras can be used, but have not been tested (because of costs involved).

results offshore

WT-Bird has been installed in one wind turbine in OWEZ (Netherlands). Initially, it was running without a camera system. Over a period of approx. one year, 10 triggers were classified as bird hits. Assuming these were medium-sized and larger birds only, the order of magnitude of bird collisions is in line with the numbers that was expected (Krijgsveld *et al.* 2011).

In March 2016, four cameras were installed, looking up from the base of the tower. An extra camera was installed on the adjacent wind turbine, oriented at the turbine where WT-Bird is running. From 15 March to 15 July, 1 bird hit was recorded. The video footage showed a feral pigeon, starting off from the nacelle, touching a rotor blade, but flying away after that. The number of bird hits seems low, but this may be accidental. After 15 July probably one more hit was detected, but this case is still under investigation. Surprisingly, when analysing the video footage described above, the researchers discovered that a small songbird apparently flying into a rotor blade was visible as well. This was not recorded as a trigger incident by WT-Bird, in line with the expectations on bird sizes of which collisions will be detected.

availability

ECN so far produced small numbers. Further production will be on demand, and can be arranged within normal time frames.

deployment

Sensors have to be placed in the rotor blades and the tower, data transmitted to a computer and from there to ECN. Currently this needs cabling in the turbine, but this may be wireless in future. The internet connection to the shore needs to have sufficient capacity. Between substation and wind turbine(s) a Gb connection should be available (This also applies to the network within the wind turbine). The minimum requirement is 2 glass fiber paths (4 fibers); 1 path for the primary data-connection and 1 path as backup.

costs

The costs of equipment for installing WT-Bird on one wind turbine will be between 50 and 100 k€, depending on improvements in the near future and camera choice. Costs of installation are not included. Installation on land, before installing the wind farm offshore, will of course be much more cost-efficient.

background information, reference projects

Information on development and initial testing in: Verhoef *et al.* (2003, 2004); Wiggelinkhuizen *et al.* (2004, 2006a en b). Recent information was obtained in personal contacts with K. Krijgsveld (Bureau Waardenburg) and H. Verhoef (ECN). The text of this fact sheet was checked by them, as the results of the current period of prolonged tests/operational use in OWEZ are as yet unpublished (report expected spring 2017).

Technology utilised in the ORJIP BCA Study

ORJIP Steering Committee: Carbon Trust, DONG Energy, EDF Energy, Eneco Wind UK, Fluor, Innogy, Marine Scotland, Scottish Power Renewables, SMart Wind, SSE, Statkraft, Statoil, The Crown Estate, Vattenfall.

Technology owner/operator: Niras and DHI have collaborated to use a suite of monitoring equipment to undertake the field observations within the BCA Study.

general description

The aim of the ORJIP BCA Study is to observe how selected priority bird species behave within and around an offshore wind farm. The observations have significantly improved the evidence base informing bird collision avoidance rates that are utilised in consenting decisions. Niras and DHI were contracted in 2014 to install state of the art monitoring equipment at Vattenfall's Thanet Offshore Wind farm to monitor micro, meso and macro bird avoidance behaviours. This included selection of suitable equipment to measure avoidance behaviour at the three different spatial scales over a two year period, and document collision impacts when possible.

Outputs to be delivered in 2017:

- empirical evidence of bird behaviour, rates of avoidance and collisions observed for 5 priority seabird species
- Data analyses and guidance to support consenting applications

For the inventory and present review the ORJIP project uses three systems that are relevant:

1. For collision detection and avoidance/flux in RSA - Thermal Animal Detection System (TADS) digital/ thermal camera systems, with radar being used to direct the camera onto the bird target, with target identification to species by specialist bird observers *ex-situ*
- 2 & 3. For measurements of fluxes within and outside the wind farm - Scanter 5000 and LAWR 25 radars, used in conjunction with laser rangefinders by offshore bird observers.

Three separate fact sheets have been compiled describing the systems. TADS will follow directly here, while the two radar systems will be described later on, following other types of bird radar.

Factsheet TADS - Thermal Animal Detection System

ORJIP Steering Committee: Carbon Trust, DONG Energy, EDF Energy, Eneco Wind UK, Fluor, Innogy, Marine Scotland, Scottish Power Renewables, SMart Wind, SSE, Statkraft, Statoil, The Crown Estate, Vattenfall

technology owners/producer: DHI as a component of the ORJIP BCA Study contractor team

general description

TADS was originally developed and used for detecting collisions of flying birds in the Danish Nysted offshore wind farm (Desholm 2003). Although in principle successful, the relatively small angle of view resulted in a small sample size. The original version of the system was reviewed by Collier *et al.* (2011, 2012). The TADS system has since been refined and has been used in Denmark. For use in the ORJIP project the TADS system was further improved, and is described below in the format it has been deployed by Niras/DHI in the ORJIP BCA.

status

TADS has been developed, tested and used offshore.

characteristics in detail

Each TADS camera system consists of a pan-tilt housing with two thermal night vision cameras, and a dual-function zoom daylight/lowlight high-definition colour video camera (Figure 2). The camera system has been programmed to use the thermal night vision cameras during the hours of darkness and switch to using the daylight/lowlight video camera when in daylight.

The zoom function allowed for 26× optical zoom, and 15x (thermal)/312× (visual) digital zoom. The related software was programmed to connect the camera with the LAWR radars located on turbines, using radar targets to trigger the camera to aim and record a video sequence of the bird(s) passing the field of view. Visual and infrared videos are recorded for 20 seconds, equivalent to a flight distance of 250-450 m with the typical flight speed of target seabirds (cf. gulls and gannets). The TADS camera operated in time intervals of 20 s, so that once a target from the radar was acquired, it tracked in synchrony with the radar target for 20 seconds.

The radar / camera connection enabled the target coordinates to be transmitted from the radar to the camera at c. 1000m range, which would then initiate recording when the distance to the bird target became less than 1000m. Coordinates of the "trigger point" were recorded for each bird target that was successfully videoed by the camera. Beyond the trigger point the radar may have lost the bird target at any point; therefore no further coordinates were recorded during the 20 second video duration. Accordingly, a subset of the total video recordings recorded have accompanying radar tracks with more than one waypoint (a fixed location with a specified longitude and latitude).

To facilitate data transfer, the radar bird tracking software was updated to track points at a rate of 24 times per minute, selecting targets based on the tracking data from the radar. Tracking information from the radar was continuously recorded to a geo-database by the system combined with images from the camera.

The range of the TADS camera was c. 1000m and the field of view is 20°, therefore with an inter-turbine distance of 500m at Thanet OWF, each of the two TADS camera systems deployed covered 8 turbines and associated rotor-swept zones. The tracks involving seabirds, which were recorded by the TADS cameras between the installation platform and the neighbouring turbines within range, were identified to species where possible, or species group taxonomic level.

technical specifications

The TADS cameras are the UK manufactured "FLIR Voyager III" as an integral component of the system. The environmental housing of the pan-tilt camera has been shown in the ORJIP study to withstand offshore maritime conditions.



Figure 2. The FLIR Voyager III unit housing both the thermal and visual cameras.

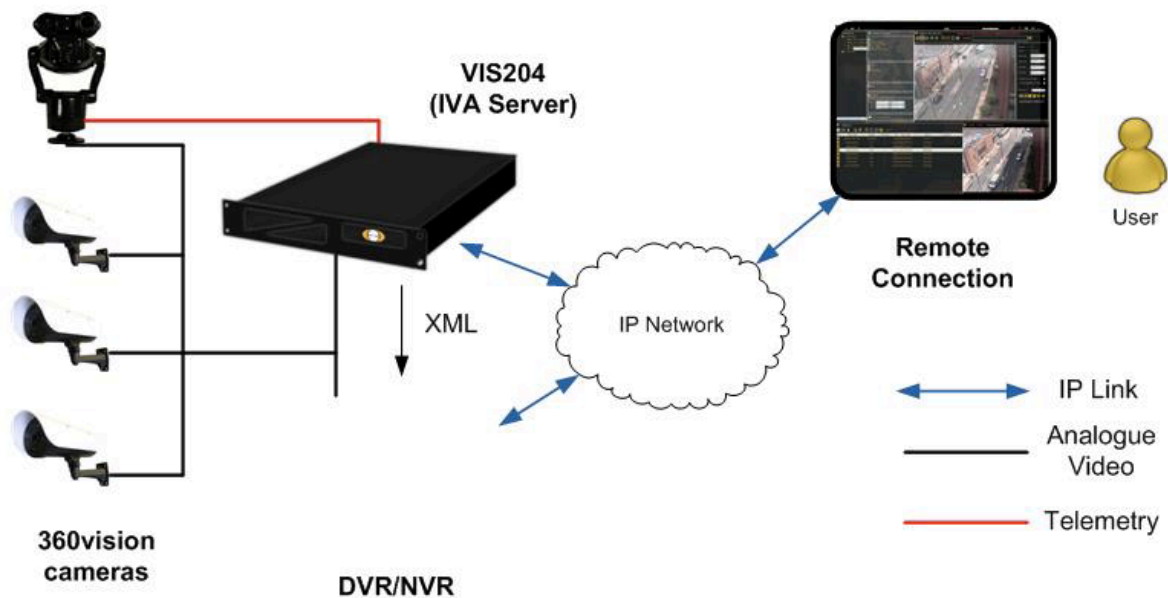


Figure 3. The configuration of the Thermal Animal Detection System (TADS).

limitations

The TADS camera system has recorded a substantial number of videos during the ORJIP BCA Study, including seabird behaviour within the rotor swept zones of the visible turbines. It should be noted however that the TADS system is still being improved on as it demonstrated a 1:200 ratio of false positives, which the engineers are aiming to

reduce. It should also be noted that the radar target acquisition resulted in most videos as "false positive records". Typically 0.5%-1% of all videos recorded contained images of a seabird, necessitating extensive screening of raw data prior to analysis.

availability

After completion of the ORJIP BCA, TADS will be available commercially from DHI.

deployment

The TADS system was being attached to the wind turbine at the turbine platform base, below the rotor swept zone. They were hard-wired to a computer inside the turbine (see Figure 3).

costs

As an indication, 100 - 200k€ could be given, but this is an estimate, accurate costs would need to be sought from the technology owners.

background information, reference projects

Public information is in online versions of presentations:

Sonja Pans *et al.* 18-05-2015: http://www.all-energy.co.uk/__novadocuments/86800?v=635675441908030000

Robin Ward *et al.* 2015: <https://www.youtube.com/watch?v=nJ-ghdtlxcE>

Factsheet VARS - Visual Automatic Recording System

owner/producer: Institut für Angewandte Ökologie (IfaÖ), Neu Broderstorf/Rostock, Germany

general description

VARS (Visual Automatic Recording System) is a motion-controlled, infrared-based videographic system for automatically detecting and recording flying birds and bats at day and night. Specially developed software ensures that the volume of recorded information is kept at a minimum. VARS is the total of hard- and software needed for fully automated operation offshore. The development of VARS was supported by the Federal Ministry for Environment, Nature Conservation and Nuclear Safety (BMU) (Schulz *et al.* 2009)⁴.

Since 2007, two camera systems are operating on the research platform FINO2 in the Baltic Sea (<http://www.fino2.de/en/research/ecology.html>). VARS has also been used in Germany's first offshore wind farm (Alpha Ventus), from 2010-2013 (Schulz *et al.* 2014).

status

Developed, tested and used in projects.

characteristics in detail

Details on using VARS at a wind turbine can be found in Schulz *et al.* (2014). Two cameras were installed (Figure 4). The camera on the nacelle was aimed directly behind the rotor blades, and in this way measured the number of birds successfully crossing the RSA. Birds entering the RSA from behind can all be detected. Together, this enabled an estimate of the number of collision victims, because these crossings were fed into the part of the Band-model describing the collision chance for birds entering the RSA. The second camera was installed as an alternative, when installing VARS on a second turbine was not allowed. The data on numbers of birds at low altitude were used as background information.

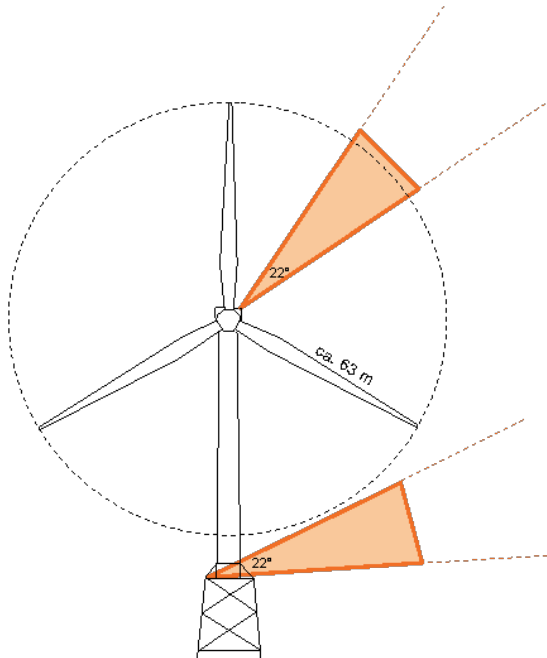


Figure 4. Location and angles of view of the 2 VARS cameras on a wind turbine in Alpha Ventus (from Schulz *et al.* 2014). The opening angle was optimized for small songbirds and could be enlarged for larger target species.

⁴ See: <http://www.ifaoe.de/en/equipment/vars/>

The camera data were used to feed the Band model to calculate collision rates. Schulz *et al.* (2014) explain in detail how this was done.

technical specifications

The main components of VARS are a camera and the software detecting birds (motion). Some information on the camera used can be found in Schulz *et al.* (2014). Most likely better cameras will be available (and used) when VARS would be used in new projects. The software is not described in detail, which is understandable as this is not 'open source' equipment.

Schulz *et al.* (2014) do provide details on reliability of operating the system. Mechanical loads/vibrations or other offshore conditions never led to failing of VARS. Power interruptions at the turbine of course did, but the systems come back automatically when power is reinstated. Only in 2012 the installation was offline on 21 days for minutes or single hours due to this. All in all this means that VARS is operating very reliably.

results offshore

Results of the deployment of VARS in Alpha Ventus are presented by Schulz *et al.* (2014). Using VARS data in combination with Band-model calculations, they calculate a collision rate of 8-14 birds per year and turbine. Integrating the data of the second camera, which allowed accounting for variation in the distribution of birds flying at different elevations, resulted in a potential collision rate of 13-29 birds per year and turbine.

Birds that were detected by VARS and of which footage was stored, could mostly be assigned to bird groups, but in many cases not to species level (see Table 3 page 50 in Schulz *et al.* 2014). Nevertheless, the results are surprisingly detailed.

availability

IfAÖ has installed systems at several sites, and will be able to provide VARS upon request.

deployment

A camera has to be attached and wired to a computer inside the turbine or platform, which is connected to a second computer. The second computer provides access from outside: internet connection to this computer is needed.

costs

Ca. € 20.000 for a single VARS with all components (without offshore installation).

background information, reference projects

Schulz *et al.* (2009, 2014) and references in there provide all information needed. The fact sheet has been sent for review to IfAÖ.

Factsheet DTBird

owner/producer: DTBird is a trademark of Liquen Consultoría Ambiental, S.L., Madrid, Spain

general description

DTBird is a self-working system for bird monitoring and/or mortality mitigation at wind turbines. The system automatically detects birds and optionally can take two independent actions to mitigate bird collision risk with wind turbines: the activation of warning sounds and/or the stoppage of the wind turbine. For this review, its capability to detect birds in the direct vicinity and in the RSA of the turbine is relevant. The system is based upon the use of HD cameras. These survey 360° around the wind turbine, detecting birds in real-time while storing videos and data. The daylight system provides continuous monitoring during daylight (light >50 lux). DTBird night system, that operates with thermal cameras, can work 24 h/day or complement DTBird daylight system.

Bird flights detected with sound are recorded and available on DTBird Online Platforms. Collision risk figures, potential collisions and species (in daylight image), can be checked in the videos. Additionally, continuous video recording of the previous 10 days is stored and available to be checked.

status

Developed, tested and used in projects. Apart from information on the producer's website, May *et al.* (2012) reported on the use of the system (in the Smøla wind farm, Norway).

characteristics in detail

DTBird is designed to detect birds in collision risk with wind turbines and to trigger actions to prevent collision. This may be stopping the turbine and/or emitting signals to deter the bird(s). Since the purpose of this review is evaluating systems for detection of birds and/or collisions, only the detection capability is relevant. For detection, DTBird daylight system has 4-8 HD cameras per wind turbine, enabling 360° surveillance. Detection distance differs with bird size (wingspan) and DTBird Detection Module model (DTBirdV4 or DTBirdV8). E.g. DTBirdV4 maximum detection distance for Northern Gannet (*Morus bassanus*) with wingspan 1,65-1,80 m is 220-240 m (360° coverage), maximum detection distance with DTBirdV8 is 380-410 m (360° coverage), and DTBirdN (night option) 160-170 m (coverage depending on number of cameras). Smaller birds are detected proportionally at smaller distances and larger birds at longer distances. DTBird reports a false positive frequency of 0.5 - 4.5/day. False positives are videos with no birds. May *et al.* (2012) reported a detection rate for all bird species, in an area where the most frequent species are eagles, of 86 - 96% of all birds in a radius of 150 m to the wind turbine and 76 - 92% in a radius of 300 m. The producers claim that DTBird detectability has been improved since 2012, and detection distances have increased.

In order to get from DTBird detection to collision rates, all videos stored from bird movements in the vicinity of the wind turbine will have to be manually checked for the fate of the bird involved. However, this also means that good information on avoiding the RSA (micro-avoidance) can be obtained.



Figure 5. DTBird Detection Module HD cameras installed on the WTG tower. Two to eight HD cameras can be installed per wind turbine. (photo from leaflet on www.dtbird.com)

technical specifications

Extensive sheets with technical specifications are available from the DTBird website.

results offshore

The website of DTBird states an offshore platform but no offshore wind turbines as sites where the system has been installed so far. Results of this have not been found/obtained yet. The system capacities will be the same as onshore, but offshore performance in relation to weather, salt, maintenance factors etc. are important as well.

DTBird started operating in offshore conditions in October 2011, with a Detection Module installation in an Offshore Experimental Station in a lighthouse in the Cantabrian Sea (Spain) and in April 2012 a second unit was installed. Since November 2011-October 2016 it has also operated in Smøla Island (Norway) for Statkraft. It has also operated from April 2015 to May 2016 in a container by the Norwegian Sea in a research project in cooperation with Fugro/Oceanor. Since November 2015 it is operating in the German North Sea for the Federal Maritime and Hydrographic Agency (BSH) Germany, in the Offshore Platform FINO 1.

availability

System is in normal production and can be ordered.

deployment

Cameras are attached to the tower of the turbine. Power and internet connection have to be arranged.

costs

DTBird units are customized for every wind farm project considering wind turbine dimensions, target species and local weather (falling blocks of ice, extreme wind, temperature). Other variables that influence in the cost are: DTBird Detection model (day/night, number of cameras), number of DTBird units and location.

background information, reference projects

Information on DTBird is based on website and available downloads: www.dtbird.com. Also the information on the use of DTBird at Smøla, as reported by May et al. (2012), has been used. The fact sheet has been sent for review to Liquen Consultoría Ambiental,S.L.

Factsheet ID-Stat

owner/producer: Calidris - Bertrand Delprat, La Montagne (Nantes), France

general description

The following description was given by Collier *et al.* (2011).

ID Stat is a system designed to detect bird and bat collisions with wind turbines that is currently under development in France (Delprat 2011). Directional microphones are placed within the hub of the turbines at the base of each rotor; these are positioned to detect sounds within the rotors. The microphones and accompanying software detect potential collisions and filter out background noise and noise from rain. Once a potential collision is registered, information such as date, time, turbine and sensor ID are stored using data loggers and a message can be sent to the user via the GSM (mobile phone) network.

At present, trials are being undertaken on Vestas turbines onshore in France. During field tests, collisions with the rotors of objects with a mass as little as 2.5 g were detected. This system solely registers the collisions of flying birds and bats with the rotors of wind turbines through audible signals. There is no verification through visual means of the nature of the event, or of the type of subject colliding. The system is being designed as a prompt for ground searches. Without such verification this system is of limited use in offshore areas.

status

ID-Stat has been described by Collier *et al.* (2011, 2012). At the time, it was in development and seemed a very promising concept and system. However, further development and testing has been delayed since then. Delprat (in e-mail November 2016) indicated that this will be taken up again in early 2017. Results might be available in the second half of 2017.

Factsheet ATOM - Acoustic and Thermographic Offshore Monitoring

owner/producer: Normandeau Associates, Environmental Consultants, USA

general description

Normandeau's Acoustic and Thermographic Offshore Monitoring system (ATOM™) is a bird and bat detection system that provides day and night monitoring in the offshore environment. This system fulfils multiple research requirements for assessing the ecological risk and impact of offshore development, and overcomes many of the survey challenges inherent in offshore research. ATOM was developed with funding from Bureau of Ocean Energy Management (BOEM), to address specific data gaps identified by the U.S. Fish and Wildlife Service (USFWS) and BOEM in early offshore wind wildlife risk studies.

status

Equipment developed and tested extensively onshore. After that, ATOM was deployed offshore (see below).

characteristics in detail

ATOM is a system designed for remote, marine weatherized, self-powered operations at buoys or fixed platforms, including wind turbines or meteorological towers. This design enables ATOM to collect data on bird and bat behaviour continuously for long-term deployments, providing essential information on day-night variation, and seasonal variation of bird and bat occurrences at actual or proposed offshore wind facilities with minimum labour effort. ATOM not only provides the essential species-specific, quantitative data on bird and bat occurrences that are needed to perform pre-construction risk and impact assessments, it is also a valuable post-construction monitoring tool.

ATOM combines three types of wildlife sensors that are analysed in combination:

- infrared (thermographic) video for quantifying bird and bat passage rates
- audible sound for bird vocalizations
- ultrasound for bat vocalizations

The thermographic component of the ATOM system is designed to calculate, record and store flight altitude and direction data of all flying animals up to 180 m. It is simultaneously capturing acoustic data, providing some species-specific identification of vocalizing birds and bats, which need to be integrated into the permitting or regulatory compliance process.

ATOM uses an automated target detection program named SwisTrack, which is adjusted to eliminate tracking of all turbine blades. At the onshore test-site, at a wind turbine, bats were observed at the blades but no collision has been observed (J. Robinson Willmott in e-mail). This means that its functionality has been tested and evaluated on land (at a turbine) and offshore (without a turbine), but unfortunately not the capacity to detect collisions of birds and bats.

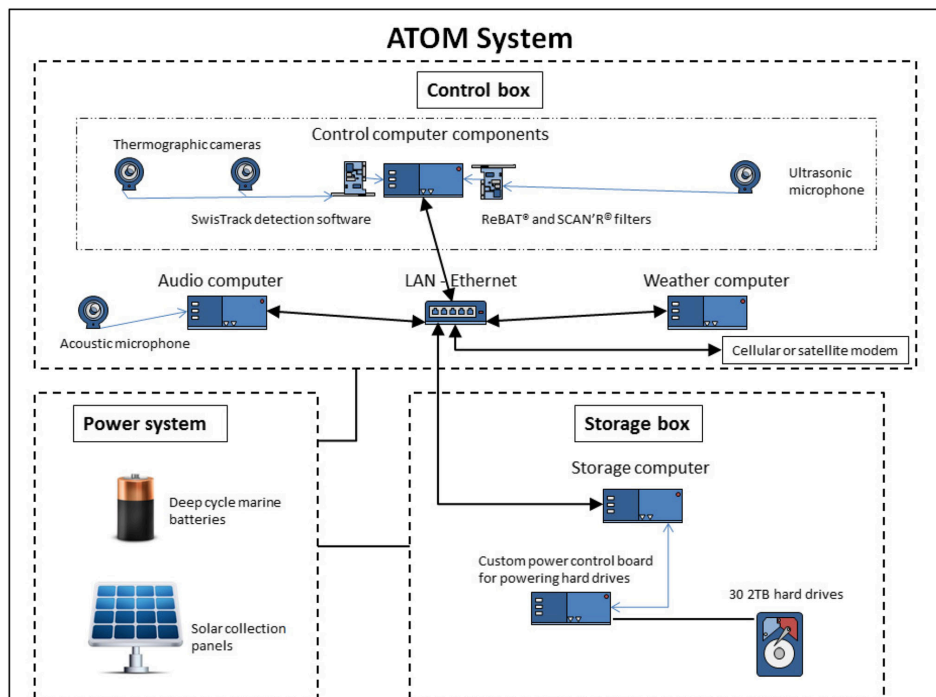


Figure 6. Composition of the central system control and communication elements of the fully integrated ATOM system. ATOM has four data collection sensors: thermographic camera, audio acoustic, ultrasound acoustic, and weather. Blue lines with arrows represent components of the computer, such as boards required to control the cameras, ultrasonic microphone, and the custom power control board that powers the storage hard drives. The power system is connected to both the control system (top box) and the storage system (bottom right box) and represented as a black line without arrows. Black lines with arrows represent ethernet communication connections between the autonomous computers. (From Robinson Willmott *et al.* 2015)

technical specifications

For extensive description of the different components and technical specifications, see Normandeau *et al.* (2014) and Robinson Willmott *et al.* (2015).

results offshore

ATOM was deployed at Frying Pan Shoals Light Tower, located 29 miles offshore of North Carolina, in the Atlantic Outer Continental Shelf. The unit survived hurricane Sandy, strong winds, and high seas and collected 2700 hours of unique acoustic and thermographic data. These data were reviewed by Normandeau's Gainesville staff and by researchers from the Cornell Lab of Ornithology. They correlated data gathered by ATOM with seasonal and weather variables and found some interesting patterns of activity. For example, both datasets -acoustic and thermographic- show that offshore bird activity significantly declines in wind speeds greater than 10 km/hr. Most birds appeared to fly higher in the evenings, with an estimated flight height increase of 1.8 times between 8 pm and 12 am, than at all other times. Migrant bird occurrence peaked in fall, with the highest density of migrating birds occurring during periods of tail wind. Species composition identified by acoustic data reflects trans-Atlantic migrants that winter in the Caribbean and northern South America, including Amazonia, but with the presence of some unexpected species such as American Pipit, Chipping Sparrow, and Dark-eyed Junco.

availability

On request.

deployment

ATOM has been tested on land and deployed for 13 months on an offshore platform. It also underwent a brief test on a buoy deployed in the Gulf of Mexico. The system functioned adequately while there was a power supply, but the solar charging system was unable to meet the system's power demands using the weather conditions at the time.

costs

On request.

background information, reference projects

Information on development, and initial testing and offshore deployment has been summarized in an extensive report: Normandeau Associates, Inc. (2014) and a journal paper: Robinson Willmott *et al.* (2015). Information was also retrieved from Normandeau's website. The fact sheet was reviewed by J. Robinson Willmott of Normandeau.

Factsheet Aerofauna Collision Avoidance Monitoring System

owner/producer: Biodiversity Research Institute (BRI) and HiDef Aerial Surveying

general description

Biodiversity Research Institute (BRI), National Center for Geographic Information and Analysis (NCGIA) at University of Maine Orono, HiDef Aerial Surveying (HiDef), and SunEdison are currently working to refine a stereo-optic, high-definition camera system with night vision capability to track flying animals in three dimensions. This system will help researchers learn how birds and bats behave around wind turbines so that developers can reduce risks to wildlife over the long term. The project is funded by the U.S. Department of Energy (DOE) under award DE-EE0006803. A final report to DOE will be publicly available in spring 2017. With the described capabilities, the system should also be able to detect collisions of birds and bats.

status

The project is an extension of a first project carried out by HiDef in UK (Mellor & Hawkins 2013). In this project proof of concept was shown, and offshore deployment tested. The development of the next step is being carried out together with BRI. Funding was received to improve hardware, software and do field testing.

characteristics in detail

Researchers employ two ultra high-resolution cameras to create a three-dimensional view of a wind turbine, the horizon, and the area surrounding the turbine. The cameras will record during daylight and also at night, using a near-infrared technology to detect animal movements. Experiments with infrared illumination are ongoing. The stereo-optic view is key in getting 3D coordinates of flying birds.

Team members from the University of Maine's Robot Interaction Lab are developing algorithms to support filtering data for large birds and other flying objects. This component is key to reducing the analysis time required due to large data sets from the camera systems. Filtering out rotor blades is still a challenge, but the system can assess micro-avoidance behaviour and collisions/mortality rates.

The goal of the study is to develop technology to determine how birds and bats respond to and avoid wind turbines, which will promote a better understanding of the magnitude of risks to wildlife at wind farms. It will also reduce uncertainty about the potential for unintended impacts during operation. In the future, these camera systems could provide a reliable way to detect bird and bat responses to wind projects offshore, where it is not possible to conduct traditional wildlife monitoring. Expected deliverables/outcomes: by the end of this project, collaborators will have moved this technology from prototype to operational system that can be used to provide detailed information about how different species respond to individual wind turbines in various seasons and weather conditions.

Provisional results show that with ultra-wide angle fish-eye lenses, which have an over a 150 degree field of view, larger birds can be detected at 500m and identified at 350m. Distance thresholds for smaller species are currently being investigated.

technical specifications

The stereo-optic camera system uses two 29 megapixel digital video cameras with fisheye lenses that are installed in a marine housing. The control system contains an uninterruptible power supply, a computer, a relay box, and an emergency buffer storage disk. The control computers pre-process the data to enable transmission back to a base station, manage the data until they are successfully transmitted, and operate the camera cleaning system. The initial data processing masks stationary parts of the image, so that only sections of the video containing moving objects are recorded, but does not compress the video. The resulting image file sizes are typically reduced by >90% requiring less than 10% of the bandwidth for transmission. A pair of full-frame colour

images are stored every 5 minutes to provide contextual information (weather, visibility, turbine orientation). Post processing involves calibrating the system for object distance estimates, marking avian object stereo pairs, calculating 3-D positions for each stereo pair, and then manually identifying birds to species or species grouping.

results offshore

Results of offshore testing of the first phase equipment have been described in Mellor & Hawkins (2013). Their results show that offshore use of the equipment was straightforward. The improvements made by BRI and partners will not affect offshore use of the system.

availability

BRI and HiDef will ensure that the system will become available for use at other sites.

deployment

Cameras have to be installed on or close to a wind turbine, see the example from Mellor & Hawkins (2013) in Figure 7. Placement on the nacelle is possible as well. A power supply is required; an internet connection allows for remote monitoring of the system. Frequent checks of the system for data drive swap and system function are necessary.



Figure 7. The Centrica prototype installed on an offshore turbine. (Figure 2 in Mellor & Hawkins, 2013).

costs

No indication available.

background information, reference projects

Initial phase by HiDef for Centrica in UK: Mellor & Hawkins (2013). Further information on the current development project was obtained from Wing Goodale, BRI. Information publicly available is at: <http://www.briloon.org/renewable/imaging>, with a full report due end of 2016. The fact sheet has been sent for review to BRI/HiDef.

Factsheet Bat Observation Technology - WMR

owner/producer: Wageningen Marine Research (The Netherlands)

general description

WMR is developing an observation system for bats at offshore wind farms. It is a combination of ultrasound bat detection and stereo-cameras which enable 3D positioning. This system is potentially also suitable to detect bird collisions.

status

The system is in development, first field tests on land are ongoing.

characteristics in detail

For ultrasound bat detection, 12 channel Avisoft software gets data from 12 microphones, 4 at 3 height levels, each differing 30 m in altitude at the wind turbine tower. Stereo cameras are used for 3D-positioning and assessing 3D flight paths. This would also enable measurements of mortality. Currently the algorithms relating to the internal and external calibration of the cameras, and filtering for movements other than rotor blades, insects and clouds are on their way.

technical specifications

Not available yet as development is going on.

results offshore

Currently tests are onshore, but the final equipment will be designed for offshore use.

background information, reference projects

<http://www.wur.nl/nl/nieuws/Wageningen-Marine-Research-examines-the-behavior-of-bats-at-offshore-wind-turbines.htm>

Factsheet Wind Turbine Sensor Unit for Monitoring of Avian & Bat Collisions

owner/producer: Oregon State University, Corvallis, OR (USA)

general description

A novel multi-sensor system has been designed and developed on the wake of an existing proof-of-concept sensor array developed and field-tested under a recent US Department of Energy grant for removing market barriers to offshore wind development. The existing system, consisting of an integrated sensor package developed around five fundamental sensor types: 1) accelerometers 2) contact microphones, 3) visual cameras, 4) infrared cameras and 5) bioacoustics microphones was tested at wind turbine sites at the North American Wind Research and Training Center (NAWRTC) at Mesalands Community College in Tucumcari, NM and the NREL-National Wind Technology Center (NWTC) in Boulder, CO.

status

An existing system has been tested. Currently an extended and improved system is under development.

characteristics in detail

The future version of the platform, currently under development, prioritizes board-level integration to significantly decrease the size, weight, and power consumption of the sensor unit. The new research platform, designed for extremely small size, will integrate a 3-axis MEMS accelerometer, 3-axis gyro, low-power CMOS imager, and contact microphone with on-board computation to enable local processing of sensor signals and detection of strikes in real time. Heterogeneous sensor fusion will allow removal of blade rotation motion artefacts and generator-induced vibrations to lower the overall noise floor. Importantly, localized computation also enables wireless transmission of only detected events instead of continuously streaming raw data, which dramatically reduces power consumption. The platform will be powered through a battery with possible integration from rotational or vibrational energy harvesting and small solar panels. This core sensor platform can be adapted for on-blade use or modified for permanent, embedded installation during blade fabrication. The unit will integrate both Bluetooth Low Energy (BLE) and WiFi modules for investigation of appropriate node-node and node-nacelle communication links, and it may include a 3G uplink for cloud-based data logging. The system can also be integrated with appropriate deterrent systems.

technical specifications

Not available.

results offshore

No offshore tests yet.

availability

Estimated by 2019

deployment

No information available.

costs

No information available.

background information, reference projects

Abstract of presentation by Roberto Albertani at the National Wind Coordinating Collaborative (NWCC) Wind Wildlife Research Meeting in Broomfield, CO in November 2016.

Factsheet 3D-Flex - Robin Radar

owner/producer: Robin Radar bv

general description

Robin's 3D Flex system consists of a horizontal S-band radar, combined with a flexible Frequency Modulated Continuous Wave (FMCW) radar. The horizontal radar identifies the presence and number of birds in time – including their location, size, direction, speed and route – up to 10 kilometres away, all around, day and night.

The FMCW radar has three modes:

- In the "Staring Mode" the radar stands still and 'stares' at a target. Traditional radars transmit a pulse while turning and then 'listen' to its echo. Robin's FMCW radar has two beams. One is continuously transmitting and the other is continuously receiving
- In the "Scanning mode" the antennas revolve around the horizontal axis continuously and creates altitude profiles based on all measured tracks in the beam. The angle of the coverage area can be chosen freely by rotating the radar around its vertical axis towards the particular area of interest. (Remotely configurable in a scheduler)
- In the "Automatic acquisition mode" the antennas revolve around the horizontal axis continuously. When an alarm track is found (based on preinstalled and customer specific alarm algorithms), the radar automatically rotates towards that target and gathers altitude information.

status

In production and is regularly being updated/improved.

characteristics in detail

The FMCW radar yields data on fluxes and flight altitudes. In theory, for measurements of fluxes, the FMCW vertical radar of Robin Radar 3D Flex could be used without the horizontal radar of the system. However, the horizontal radar provides information that can be essential to interpret the flux data from the vertical radar. This is a choice that has to be made in each separate project.

The algorithms in the Robin Radar software detect the birds in the radar signals, track these bird echoes over time, and the data are stored. It is also possible to store raw radar data for later re-analysis.



Figure 8. Robin Radar 3D Flex in trailer-version, taken from www.robinradar.com.

The horizontal radar tracks larger birds and flocks of birds to a distance of max. 10 km, while smaller birds can be seen to approx. 4.5 km. The vertical FMCW radar has slightly lower reach, but as normally an altitude of max. 2 km is of interest this is not a problem. Robin Radar systems can be operated remotely when a sufficient fibre optic cable or other type of internet-connection is available. Data are stored and analysed, and the standard options for data viewing and analysis are growing over time.

technical specifications

See sheet in Snoek (2016).

results offshore

3D Flex has been used on sites directly adjacent to the sea (on dikes or beaches), and has recently been, or will soon be installed offshore. No public reports with data analysis and information on the impact of clutter on bird data are available. There are good reasons to expect that 3D Flex will yield good data offshore as well, although all bird radars in horizontal mode will have clutter issues caused by waves. Robin Radar claims to have made important improvements on this, but no project data/reports are yet available where this new software has been applied. For offshore applications Robin Radar has developed together with CHL a special S-band antenna, (same specs, but different beam width) which is able to cope, to a large extent, with the sea clutter issues. After being comprehensively tested in 2016, this antenna will be installed on an offshore research rig, FINO1, as from December 2016.

availability

Can be ordered, there is regular production.

deployment

No specific information available.

costs

No information available.

background information, reference projects

ROBIN radar has the following reference projects specifically in the windfarm industry: Acciona- Tafila-Spain (onshore) EVN- Kvarna-Bulgaria (onshore), BSH- FINO1- Germany (offshore), Suomen Hyöthituuli Oy- Pori- Finland (onshore), Eesti- Kinu Island-Estonia (onshore). From these projects there were no reports publicly available at the time of writing this review.

Factsheet Merlin Bird and Bat Radar

owner/producer: DeTect Inc.

general description

Merlin Avian Radar System uses a combination of a 200 watt solid-state Doppler S-band Horizontal Surveillance Radar (HSR) and a 25 kW X-band Vertical Scanning Radar (VSR). Radar data are real-time analysed by DeTect's own algorithms. This enables simultaneous horizontal and vertical bird detection and tracking with full data recording to SQL dataserver system.

MERLIN is designed for monitoring bird activity at a site, but can also connect to a wind farm's SCADA control system and initiate curtailment of WTs if bird collision risk is considered too high. This add-on feature is called MERLIN-SCADA.

status

In production and is regularly being updated/improved.

characteristics in detail

The Vertical Scanning Radar yields data on fluxes and flight altitudes. Theoretically, for measurements of fluxes, the vertical radar of Merlin Radar could be used without the horizontal radar of the system. However, the horizontal radar provides information that can be essential to interpret the flux data from the vertical radar. This is a choice that has to be made in each separate project. Examples from both have been applied at the North Sea: horizontal and vertical radar at Meetpost Noordwijk and OWEZ, and vertical radar only at K14 gas platform.

There are technical differences between subsequent versions of Merlin Radar systems, as DeTect is continuously improving its systems. This concerns hardware and software/algorithms. However, MTR measurements and flight altitude profiles with vertical radar are relatively stable and can generally be compared between versions (same range settings have to be used at the sites being compared). Merlin Radar detects bats well, but does not automatically categorize them as distinct from birds.

Merlin systems have been applied offshore in The Netherlands (see above) and more recently also in Belgium by MUMM in the C-Power wind farm.

Using Merlin Radar in OWEZ in the end yielded good results, but this was only possible at the cost of a substantial post-processing and analysis effort by Bureau Waardenburg. Current database facilities by DeTect have improved a lot since this 2003 project.

For the most recent series of Merlin Radars, DeTect has been using solid state radars instead of magnetron radars. Each has advantages and disadvantages.



Figure 9. Merlin Radar at the OWEZ metmast, overview and details of vertical and horizontal radar respectively (photos M.J.M. Poot and K.L. Krijgsveld).

technical specifications

See sheet in Snoek (2016).

results offshore

Research at Meetpost Noordwijk, OWEZ and K14 has been published extensively, see reference projects below. Especially the vertical radar data, which are most important for measurements of fluxes/MTR, were of very good quality. Analysis of these data revealed useful patterns. The data-set can also be revisited, as was done e.g in Krijgsveld *et al.* (2015), on migration peaks in relation to mitigation in new Dutch offshore wind farms.

availability

Can be ordered, there is regular production. Production lead time is typically 5-6 months.

deployment

The Merlin Avian Radar System requires a stationary location from which to observe bird activity. For offshore wind farms, this may be a power substation, a Met Mast, or even the shore for near-shore locations. If fibre-optic communication lines can connect the radar sensors to shore, then the processing computer system may be more securely located on shore.

costs

Costs vary by project but are generally between USD \$500K to \$1M; including purchase, delivery, installation, commissioning, training, and 1 year of warranty, technical support, and data analysis/reporting support. Support services can be added to the typical 20-25 year life of a project.

background information, reference projects

Extensive reports are available on the projects related to OWEZ, the first Dutch offshore wind farm. Baseline monitoring took place at offshore platform Meetpost Noordwijk. See Krijgsveld *et al.* (2005, 2011), Fijn *et al.* (2012), and also Fijn *et al.* (2015).

Factsheet **BirdScan MR1**

owner/producer: Swiss BirdRadar Solution AG

general description

BirdScan MR1 is a compact radar system for the quantitative long-term monitoring of birds and bats. BirdScan MR1 uses a vertically directed conically shaped wide aperture beam with a nutating movement.

status

Developed, tested and in use in several projects in different countries.

characteristics in detail

Birds and bats are detected using pulsed radar that emits beams vertically across a conically-shaped field from a corrugated Horn-antenna with a wide aperture angle. BirdScan consists of a transmitter/receiver unit and a computer and analysis unit. The system can be monitored remotely if connected to the internet.

The setup of BirdScan MR1 allows to record the following information for each target:

- Precise recording of target's height above ground.
- Wing flapping pattern which is necessary to exclude non-bird and non-bat echoes like insects and allows classification of bird echoes into sub-groups. See Figure 10.
- Precise knowledge of surveyed volume which is necessary to estimate the number of birds aloft per volume, i.e. to compute Migration Traffic Rate for specific altitude layers (birds / horizontal km * hour). See Figures in Appendix 1.
- Flight direction and speed of target is obtained from the nutating beam.
- Shape of target (long vs. round) is obtained from circularly polarized beam.
- X-band radar which can detect even small birds (e.g. small passerines) and bats up to 1000 m and large birds (e.g. gulls) up to 2000 m.

Horizontally or vertically rotating bird-radars only illuminate a target for a fraction of second and wing-flapping pattern cannot be recorded. Therefore non-bird echoes like insects cannot be excluded properly. In traditional rotating radars the surveyed volume is generally less well-defined. Computation of MTR with BirdScan is probably more precise.

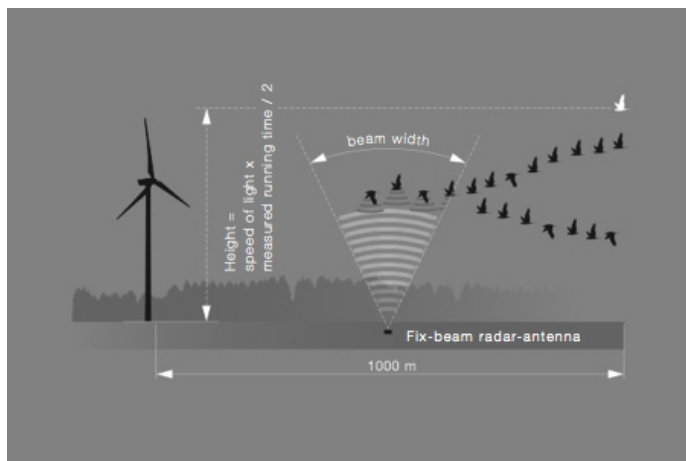


Figure 10. BirdScan schematic overview.

Examples of offline analysis are in Appendix 1.

technical specifications

See sheet in Snoek (2016) and Appendix 1.

results offshore

BirdScan MT1, the precursor of MR1, has been used, together with VARS, by Schulz *et al.* (2014) at Alpha Ventus. It was situated at the FINO1 research platform (Figure 11). Offshore deployment therefore has been proven successful.

Schulz *et al.* (2014) report how they used the radar and how data were analysed. They were able to distinguish automatically between groups of bird species, and present MTR data for these species groups.

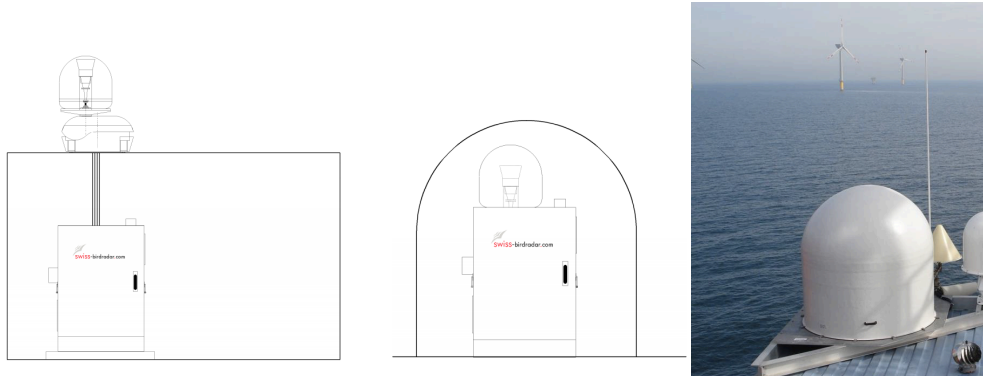


Figure 11. BirdScan MR1 (left and middle) and MT1 (right). MR1 left: Server and processing module protected in a container; radar antenna on top of container protected by a small Radome. MR1 middle: Standard compact MR1 system protected by a larger Radome (approx. 1.5 m width * 1.6 m height). MT1 right: as it was situated at the FINO1 research platform.

availability

In production and available.

deployment

The MR1 radar can be placed as close as 150 m off the turbine. Like for any radar, a rotating blade within the measurement range would produce strong disturbances and would make it hard to properly detect all birds.

The MR1 has a relatively large aperture beam and is designed to look vertically; tilting it would increase detection of clutter signals from the sea surface. As an alternative the MT1 system (Figure 11 right) could be used, which has a narrower beam and can be used to look sideways.

costs

To be obtained from Swiss BirdRadar Solution AG.

background information, reference projects

Schulz *et al.* (2014) and references in there, together with the website of the producer provide information. The fact sheet has been sent for review to Swiss BirdRadar.

Factsheet Birdtrack

owner/producer: Strix, Portugal

general description

Birdtrack is a dual radar system for automatic detection and tracking of birds and bats. It is an automatic tracking system, providing data collection and analysis of long time series with classification of radar targets into groups of species.

status

Developed and available.

characteristics in detail

Birdtrack® is a radar system solution for automatic detection and tracking of bird and bat targets for surveys, monitoring and mortality risk mitigation. Birdtrack solution is a combination of the Birdmonitor® application with the dual radar configuration into a solution for detection of bird and bat activity with analysis of flight patterns, georeferenced movement parameters, pathways, altitudes, mean traffic rates and other environmental conditions. Birdtrack radar system can operate autonomously and be remotely accessed. It can be configured for portable- and fixed-mounted stations with optional remote access capabilities.

Birdtrack dual radar system consists of an X-band radar (9410 MHz) and an S-Band radar (3050 MHz). The S-band radar scans in horizontal surveillance mode. This radar configuration is designed to obtain precise bird and bat trajectories. It accurately maps trajectories of individual bats, birds or flocks, delivering flight speed and other parameters used in target identification (bird and bat species or groups of species). The X-band radar scans in vertical mode. This radar configuration is designed to obtain flight altitude, traffic flow and complementary data for target identification.

Birdmonitor is a software application for radar bird and bat detection developed by Strix in collaboration with their technology-oriented partner INOV research institute. Birdmonitor incorporates signal-processing technology and advanced tracking algorithms that optimize automatic detection, tracking and classification of bird targets. It includes modules for automatic data grabbing, calibration, ground and weather clutter filtering. Its site-specific adaptability renders very high detection efficiency and reduces significantly errors in target classification. Birdmonitor includes a database management system that stores very large datasets of georeferenced individual flight trajectories and associated parameters that allows data export for robust statistical analysis.

technical specifications

General specifications:

Horizontal radar: S-band radar, frequency 3050 MHz, 30 kW peak pulse power, beam width 2.3°-2.5° (horizontal) and 25° (vertical).

Vertical radar: X-band radar, frequency 9410 MHz, 25kW peak pulse power, beam width 0.90°-0.95° (horizontal) and 20° (vertical).

Birdmonitor® radar bird detection and classification system with calibration capabilities. For details, see sheet in Snoek (2016).

results offshore

Birdtrack has been used offshore from the coast at the Azores and in Portugal.

availability

Available from Strix.

deployment

No specific information available, equipment has to be installed on platform or wind turbine.

costs

On demand regarding project's characteristics.

background information, reference projects

references to offshore use:

Radar survey of Cory's shearwater population in Corvo island, Azores, Portugal: Gerlades *et al.* (2015)

Windfloat project, Portugal: STRIX & Agripro ambiente (2013) and Agripro ambiente & STRIX (2016).

Selected references for Birdtrack on land:

"Wind turbine shutdown on demand operations and bird migration monitoring in the Gabal el Zayt Wind Farm (200 MW), Egypt", developed for GAMESA and NREA – New and Renewable Energy Authority.

"Guidance on the use of "shutdown on demand" as an effective tool for both the wind energy sector and to conserve emigrating soaring birds (MSS 's) in the Gebel el Zayt area (Egypt)", developed for BirdLife International.

"Developing and testing the methodology for assessing and mapping the sensitivity of migratory birds to wind energy development", developed for BirdLife International within the project "Mainstreaming Conservation of Migratory Soaring Birds into Key Productive Sectors along the Rift Valley/Red Sea Flyway".

Factsheet DHI Bird Detection System with Scanter 5000

ORJIP Steering Committee: Carbon Trust, DONG Energy, EDF Energy, Eneco Wind UK, Fluor, Innogy, Marine Scotland, Scottish Power Renewables, SMart Wind, SSE, Statkraft, Statoil, The Crown Estate, Vattenfall.

Technology owner/operator: Terma (hardware), DHI (software)

general description

The SCANTER 5000 is a solid state radar with an enhanced tracking capability. Within ORJIP BCA it is being used together with DHI's Bird Tracker software.

status

Available, at the moment not clear in what form the technology will be available on the market after the ORJIP BCA study.

characteristics in detail

The SCANTER 5000 is a solid state radar with an enhanced tracking capability. The development of solid state technologies has made it possible to conduct free and flexible frequency selection over the full band (9.0-9.5 GHz) with the possibility of up to 16 sub bands, providing enhanced capacity to suppress sea and ground clutter, and rain, in comparison to a magnetron-based radar such as the LAWR 25 radar (see Section 2.3).

Several filters were applied to the SCANTER radar raw output. Coherent Doppler-based processing reduced or eliminated signals from slow moving and stationary objects. To reduce sea waves, precipitation and noise, multiple statistical ordered CFAR filters were utilized (Terma 2012). CFAR filters were also utilized to reduce the time-side lobes from the pulse compression, in addition to the minimal antenna side lobes. Designed into the SCANTER antennas, a Sea Clutter Discriminator was utilized to detect small targets normally hidden in sea clutter.

Furthermore, the radar utilised a very short range cell size from the broad banded pulse compression, which reduced influence from precipitation. The radar utilised multiple frequencies (frequency diversity) transmitted with a time interval allowing time diversity, enhanced when combined with the frequency squint of the SCANTER antennas. This technique smoothed out clutter and enhanced targets. The radar also utilised an interference filter, which reduced noise from other electromagnetic sources nearby.

Using a fan beam radar (rather than a tracking radar) and high resolution classification of bird signals, by cross correlation with known bird radar signatures, reduced the chance that turbines and rotors interfered with the tracking of birds.

The radar software consisted of a Tracker and Doppler Enhanced processing software, while the BirdTracker GIS-based software enabled real-time tracking and geo-referencing of bird movements, enabling tracks of individual birds or flocks to be followed on background video images. The videos were produced using a frame grabber connected to the radar and bespoke software provided the video as a background image on the PC-screen with the radar position in the centre.

While the maximum detection range of the SCANTER radar was 20km (depending on bird species), the scanning range of this radar was set to 12km in order to reduce detection limitation artefact within 6km from the radar location.

technical specifications

See sheet in Snoek (2016).

limitations

Some limitations have been identified through the ORJIP study and will be documented in the report to be published in late 2017.

availability

Available from Terma and DHI.

deployment

No specific information, radar has to be installed on a platform, wind turbine or other structure.

costs

No information available.

background information, reference projects

Public information is in online versions of presentations:

Sonja Pans *et al.* 18-05-2015: http://www.all-energy.co.uk/__novadocuments/86800?v=635675441908030000

Robin Ward *et al.* 2015: <https://www.youtube.com/watch?v=nJ-ghdtlxcE>

Factsheet DHI Bird Detection System with LAWR 25

ORJIP Steering Committee: Carbon Trust, DONG Energy, EDF Energy, Eneco Wind UK, Fluor, Innogy, Marine Scotland, Scottish Power Renewables, SMart Wind, SSE, Statkraft, Statoil, The Crown Estate, Vattenfall.

owner/producer: DHI

general description

The system consists of Furuno 2027BB 25kW magnetron marine surveillance radars, which can be positioned horizontally and vertically. DHI has its own proprietary signal processing hard- and software, enabling selecting and tracking bird echoes. In ORJIP horizontal radar only has been used (Interim report 4). LAWR originally stands for Local Area Weather Radar, developed by DHI.

status

In use in several DHI projects. Description below is from the ORJIP project.

characteristics in detail

The LAWR radar is a magnetron-based radar, and was used both for observer-aided tracking and automated tracking as a component of the TADS system (described in accompanying factsheet). It allowed real-time tracking from the radar using the BirdTracker software, and a separate software package used for running the automated radar tracking. The LAWR radar was sensitive to sea clutter in sea states higher than Beaufort 2, then becoming more difficult to use in comparison with the SCANTER 5000 radar.

The detection probability of the LAWR radar peaks in the middle of the scanned range, and reduced either side of the optimal detection peak, as shown in Figure 12.

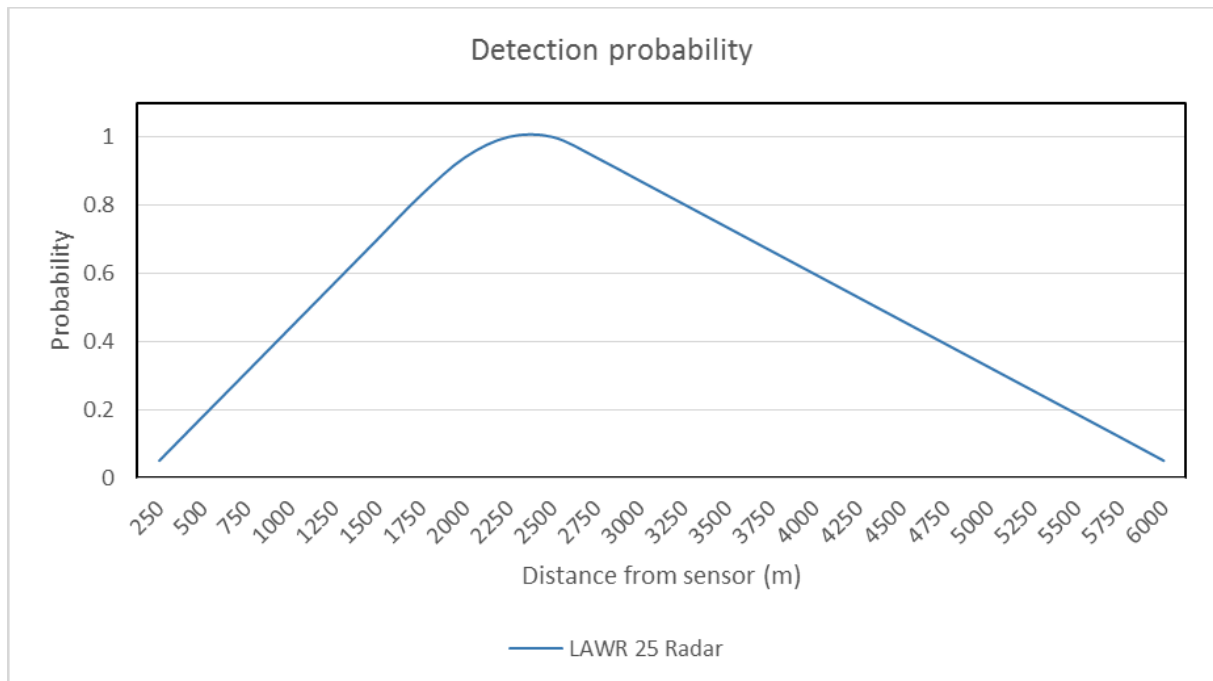


Figure 12. Detection probability curve for the LAWR radar using a 6 km scanning range, which is based on recordings of seabirds in offshore parts of the Baltic Sea (FEBI 2013).

In comparison with the SCANTER radar, the LAWR radar has a very different detection probability curve, with low detectability close to the radar, increasing up to a peak level between 1,500 and 2,750 m, where after dropping again (Figure 12, FEBI 2013). This theoretical curve is affected by changes with the aspect of the flying bird and different weather conditions. As a result of the vertical angle detection of the radar beam, low-flying (< 10m altitude) seabirds could not be detected closer than 85m from the LAWR 25 radar sensor. For the same reason the maximum height recorded of seabirds flying at 1,000m distance was 175m altitude. This is also depending on the height of radar deployment.

technical specifications

See sheet in Snoek (2016).

availability

After completion of the ORJIP BCA LAWR will be available commercially from DHI.

deployment

No specific information, radar has to be installed on a platform, wind turbine or other structure.

costs

No information available.

background information, reference projects

Public information is in online versions of presentations:

Sonja Pans *et al.* 18-05-2015: http://www.all-energy.co.uk/__novadocuments/86800?v=635675441908030000

Robin Ward *et al.* 2015: <https://www.youtube.com/watch?v=nJ-ghdtlxcE>

5 Review

5.1 Detection of bird collisions

Field measurements of bird mortality at wind farms are essential for evaluating the adverse risk of wind farm operation on bird populations as well as improving the modelling of potential bird mortality for designing future new wind farms. On land, this has been achieved by collecting carcasses underneath turbines at many different sites. Offshore such searches are impossible. Alternative methods of detection of bird fatalities are challenging. In recent years several initiatives have endeavoured to identify technological solutions to tackle this problem.

In the inventory above the currently available systems have been described. To date, few systems have been shown to systematically detect and record bird collisions at offshore wind turbines. These are WT-Bird and TADS. In addition the VARS system has reliably recorded all birds entering the rotor-swept area, enabling accurate estimates of bird mortality. ATOM has the capability, but no actual collision has been reported yet. In the near future, at least the ACAMS system will join the list and very likely the system Oregon State University is developing. ID-Stat, if further developed, may join this list as well.

The number of systems actually in use may seem small. However, the list as presented here is really a big step forward as compared to e.g. 4 years ago, when Collier *et al.* (2012) concluded '*Currently, no system offers all the requirements specified in [...] and only two are known to be undergoing testing at offshore turbines*'. In these recent years, three systems have now delivered empirical figures of fatality rates at offshore wind farms.

WT-Bird detects the potential bird collisions, with apparently a low number of false positive incidents. So far it has an important limitation: birds smaller than approximately starlings and thrushes are not being detected. Its camera positions enable sampling of footage e.g. on days with intensive songbird migration for RSA passage rate and collisions of small birds. If the research question is focussing on larger birds, the system can be high on the list.

TADS records collisions of all species. As the ORJIP project has targeted priority seabird species, which are typically larger birds, no songbirds were systematically tracked by the observers at the radars. However, TADS data on songbirds are available.

VARS does not directly detect collisions, but precisely records the birds passing the RSA and using part of the Band-model collision rates are calculated. This is, certainly in the current situation and in comparison with the other systems available, providing good quality data. Using this part of the Band-model is not introducing large errors, and micro-avoidance data are gathered in the same time with the collision data.

ATOM has been extensively tested, but only on land at a wind turbine and no collisions were recorded in the test period. However, both on land and at sea the system was functioning properly, and the collision detection properties should be further tested/demonstrated.

Also, ACAMS of BRI/HiDef will soon become available. In comparison with other camera-based systems it has additional capacities (3D tracking, relevant for behaviour/fluxes). Collision detection will be a feature, but no field tests are available yet.

The development of a wind turbine sensor unit for monitoring of collisions by Oregon State University is also worthwhile to mention and keep track of. It has a combination of sensor types and is potentially able to detect collisions of small songbirds as well.

ID-Stat is still in early stages of development.

The positive outcome of this review is that there are now several systems available that have proven to detect bird collisions offshore, and some systems in different stages of development. So the measurements can be done, and there is a choice in equipment. The final choice may then be determined by options for combination with other tasks/questions, species on target, budget or other factors. Each system still has its limitations, but from the current situation where our knowledge on bird mortality at offshore wind turbines is very limited, a step forward can now be made.

5.2 Detection of bat collisions

So far, there is no system that has demonstrated detection and recording bat collisions at (offshore) wind turbines. However, some of the systems detecting bird collisions could conceivably also be capable detecting bat fatalities.

As (some) bats are killed without actually colliding but because of barotrauma, systems using cameras for detection and recording will be the only option to do so in future. As such, VARS, TADS, ATOM and ACAMS should be feasible. These systems do not select for bats. However, as footage for all positive triggers has to be checked anyway, bats will be seen when the footage is good enough to distinguish bats from small birds.

Common bat (sound) detection will be needed on site to know which species are in the vicinity at the time of any bat being recorded, as the camera footage almost certainly will not provide certainty on the species of bat involved.

Systems in development for this purpose are those of Oregon State University (USA) and Wageningen Marine Research (NL).

5.3 Measurements of bird fluxes (MTR)

Flight movements, expressed as fluxes (MTR), will have to be monitored at different spatial scales.

Firstly, birds approaching the RSA will have to be observed in order to assess micro-avoidance rates on a species-specific level. When entering the RSA they can either become a collision victim or escape safely. Within the wind farm, using radar is difficult, and certainly at and in the RSA camera-based systems are to be preferred. TADS, VARS and CAT can be used for this task.

Measuring behaviour and numbers of flying birds within the wind farm is the next task, scaling up the view spatially. Within the wind farm, but further from the turbines, cameras may have issues with field of view: if that is not big enough, not enough observations can be made to get the dataset one needs to be able to quantify behaviour. TADS (in combination with radar) can fulfil this task. A modified VARS system can probably do so as well, but the present information does not indicate this with certainty. Finally, CAT is designed to gather these data on flight patterns and behaviour within or just outside the wind farm.

Also, some of the bird radar systems are capable of doing so. The LAWR radar, which is used in combination with TADS, is capable of following bird tracks from outside the wind farm towards the turbines. It can be used to track individual birds or groups, which is providing information on flight behaviour, but can also be set to measure all birds. Other radar types, especially the ones able to be aimed upwards (vertically) are especially good in providing altitude-specific measurements of numbers of flying birds (Robin Radar 3D-Flex, Merlin Radar, BirdScan, BirdTrack).

Measuring fluxes of birds outside the wind farm is typically something where dedicated bird radar is needed and camera-based systems are currently no longer a real option.

Robin Radar 3D Flex, Merlin Radar, BirdScan, BirdTrack and DHI’s radars have vertically oriented radars that are well equipped to do these measurements. All these systems are to some extent limited in identification of bird echoes at species level.

5.4 Measurements of bat fluxes (MTR)

Currently there is no system available to do these measurements. Cameras in combination with bat sound detection may be the solution, but software has to be developed and behavioural studies have to be completed before this will be readily available. Otherwise, cameras with software detecting ‘flying objects’, which will be bats but birds as well, will have to be used. There are several options and developments in this. All selected footage with movements then will have to be checked afterwards.

5.5 Overview

In the sections above, systems have been evaluated for capacities related to four different types of field measurements. As some of the systems have been mentioned several times, because they can be used for different measurements, a summary table seemed worthwhile and is provided below.

Table 1. Comparison of systems; see text.

	collisions			flux
	birds	bats	birds	bats
available				
<i>Acoustic/camera</i>				
WT-Bird	+		(A)	(A)
TADS	+	+	A(B)	A
VARs	+	+	A(B)	A
DT-Bird	+			
ATOM	+	+	A	A
<i>Radar</i>				
3D Flex Robin Radar			BC	B?
Merlin Bird and Bat Radar			BC	B?
BirdScan MR1			BC	B?
Birdtrack			BC	B?
DHI Scanner 5000			BC	B?
DHI LAWR 25			BC	B?
in development, tests ongoing				
ACAMS	+	+	AB	A
Orgeon State	+	+	A	A
in development				
ID-Stat	+			
Wageningen Marine	+	+	A	A

+: system can do so, see fact sheet for information on details and limitations

A: flux measurements at RSA

B: flux measurements within wind farm

C: flux measurements outside wind farm

5.6 Combinations and options for the requested monitoring programme

Within the Wozep programme, Rijkswaterstaat is aiming at integrating field measurements of collisions/fatalities amongst birds and bats with measurements of behaviour and fluxes at different spatial scales. In the end, both avoidance and collision rates are the result of these measurements.

In the inventory and review above, systems have been presented in relation to each of these measurements. For the project as a whole, systems will have to be combined as smartly as possible.

For birds, up until now, already three of such combinations have been applied offshore: VARS with BirdScan (Schulz *et al.* 2014), WT-Bird with Merlin Radar (at OWEZ, NL, unpubl. data ECN and Bureau Waardenburg), TADS and DHI Bird Radars LAWR and Scanter (at Thanet, UK, ORJIP, unpublished). Of course, many other combinations are possible as well.

Choosing between systems for collision detection may depend on the species of interest in the programme at hand, on technical issues, on the moment on which equipment has to be deployed, on the need to combine with information on micro-avoidance, and so on.

Some of the bird radar systems are relatively comparable, and individual comparison or combination with other research questions may determine the choice. If focus is on birds only, the choice might be different than when bats are involved as well. Also, systems installed to switch off turbines when birds or bats fly in densities where collision risk is considered too high, may be used for research purposes as well.

The review so far has already made clear, that for research on birds the situation is much better than for bats. No system is available that is designed specifically for detection of bat fatalities. Camera-based systems might be able to do so, but have not been tested for it - and data will have to be retrieved from between bird footage. If birds are also under study at the same time, this might be no problem, but if the measurements are aimed at bats only it might be a real disadvantage. Software options of these systems have to be checked for this.

The same holds for measurements of numbers of passing bats: flux measurements are not in the current range of bat registrations in the field. Detection of activity, through recording the sounds of bats, is common. From this, relative activity patterns may be generated, but calculating numbers passing by is something different. Also, the detection range is small.

This review is not aiming at choosing one 'ideal combination' or preference. On the contrary, showing that there are multiple options, which may have different positive characteristics and challenges, was the main goal. In the preceding paragraphs, the systems available have been discussed following the inventory and the information in the fact sheets. For a specific project, it should now be possible to compile Terms of Reference that define the task at hand but also leave a choice of equipment to be proposed.

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Appendix 1 Additional information BirdScan MR1

This information is in addition to the overview in Snoek (2016).

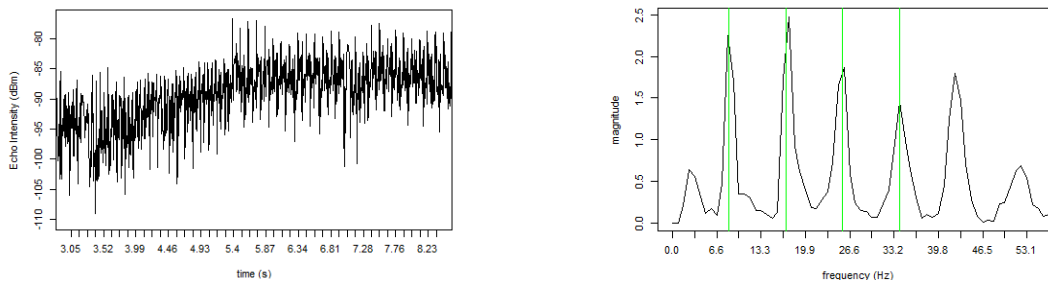


Figure 2.1. Example of echo from a bird recorded by MR1 system (left). The wing-flapping pattern is recorded with the signal and can be extracted automatically with our analytics modules (right), here a continuously flapping bird with 8 wing-beats per second.

High quality offline-analytics: BirdScan MR1 radar systems can reliably detect even small passerines and small bats. Hundreds of thousands echos per month can be recorded. To leverage the full potential of this data, our experts can provide detailed off-line analytic services to crunch the data and deliver high quality analyses and reports for impact assessment reports or scientific publications. A few examples of display items are shown for illustration in Figures 2.2a-c.

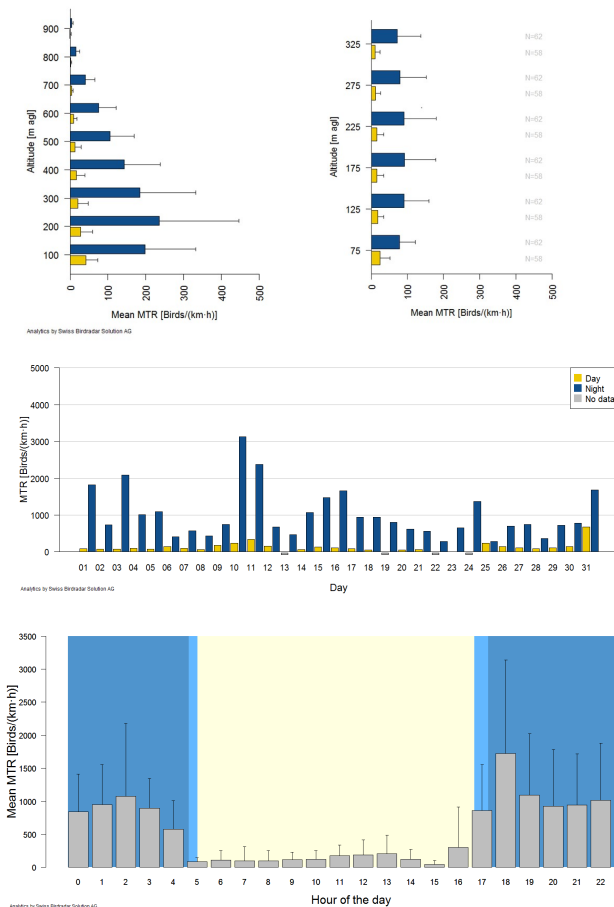


Figure 2.2a. BirdScan radar systems provide a precise estimation of altitude above ground of each detected bird or bat allowing to compute Migration Traffic Rate for specific altitude layers. Here standard altitude of 100 m (left) or 50 m (right).

Figure 2.2b. Based on onset of dawn and dusk, the Migration Traffic Rate can be computed on a per day basis. Here for altitudes in 50 - 1000 m. Custom altitude and time resolutions are also possible.

Figure 2.2c. Per-hour mean MTR can be computed from seasonal or monthly data. Relevant information can be plotted jointly (here light/dark periods).

BirdScan MR1 Product Specification:

radar system	marine radar
transmitting power	25 kW
transmitter frequency	X-band fixed 9.4 GHz
antenna	special 20 dB
antenna system	rotating vertically
max. range (distance)	2000 m
resolution in space	5 m
spatiotemporal distribution:	
-height	Yes
-speed	Yes
-direction	Yes
-bird classification	Yes
electrical connection	1x230V (400W)
weight	Approx. 100 kg
operation	automatic 24 h
climate kit (optional)	HVAC (+1500W + 30kg)
environmental design	MIL STD 810 F
area of application	research, environmental studies