

<i>Organisation</i>	TNO division <i>Defense, Security and Safety</i>
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Introduction

At the end of 2007 offshore wind farms with a total capacity of about 1,100 MW were operational in Europe, while new projects are being added regularly in a number of countries. The EU's objective is to have 40,000 MW offshore wind power operational by 2020 in European waters.

Environmental Impact Assessment (EIA) forms an integral part of each offshore wind farm planning stage, and these studies include bird migration monitoring. Until today there were no effective radar-based monitoring systems available with a key operational focus at tracking bird movements. As part of the WE@SEA research program TNO division *Defense, Security and Safety* engaged into developing a dedicated bird tracking radar system under the product trade name ROBIN Lite. One of the main project and product development objectives was that ROBIN Lite enables the continuous and systematic registration of bird migration in a predefined area around offshore wind farms. A second main project objective is that the radar system can be remote controlled, operate independent from unmanned offshore wind farms, and that the bird-migration data can be transmitted onshore.



Despite the fact that the Robin Lite system development, testing and optimizing process has not been completed yet, substantial commercial interest is expressed already from Dutch as well as foreign parties. The project execution process itself also faced a number of setbacks, for instance with regard to signal interference issues. That necessitated intermediate system redesign, which in turn required additional funding exceeding the initial budget and also caused considerable project progress delay.

Due to the importance attached by TNO towards accomplishing a fully operational and tested ROBIN Lite system, a decision was made to fund this crucial last project stage towards commercialisation from internal TNO resources.

ROBIN Lite bird radar development objectives

During the next decennia a large number of offshore wind farms are planned in the North Sea. It is also envisaged that offshore wind farms will in future provide a significant share of total electricity demand in the Netherlands. However, environmental effects and potential constraints are without exception closely linked to planned as well as operational (offshore) wind farms.

Project developers are obliged to conduct an EIA, aimed at quantifying any positive and negative environmental effects linked to the building and operation of offshore wind farms. Such an EIA in addition has to contain specific project measures aimed at alleviating and/or significantly reducing these negative wind farm effects.

An important part of an EIA is dedicated towards the potential impact of offshore wind farms to fish, birds, sea mammals and other water born organisms. With regard to local effects on birds like accidental collisions,

habitat loss, and/or wind farms posing a barrier to migration routes and general freedom of movement all need to be quantified. Until today quantifying all these effects has proven very hard to accomplish. This is true for bird monitoring in general but especially tracking offshore bird migration offshore is highly complex and a very time consuming process. It is in fact a combination of the logistical efforts required (i.e. transportation and local stay) and specific challenges linked to observing bird movements during night hours above the water surface.

Radar for bird observation

Radar has always been regarded one of the potentially most important available tools for bird observation and especially bird flight movements in a marine environment during the dark. Radar observation as a key advantage is fully independent of visual conditions (i.e. darkness, foggy weather). It is in addition possible to register and electronically store all bird movements at random and scattered in a wide area, and low as well as high altitudes. Finally with the aid of high-level automation tools key variables including flight directions, flight speeds, and bird flock densities can be quantified.

Bird radar systems require sufficient range to cover a given wind farm object and a wide area stretching several kilometres around it in order to adequately track and analyse bird migration behaviour. Today's bird radar systems are all based upon maritime 'shipping-type' radars. Under ideal circumstances these systems are indeed capable to detect small objects including birds above land at a range spanning several kilometres. However, above a water surface the detection range is often much more limited due to wave reflection effects. Under regular sea state (= wave height) conditions, and in a combination with wave reflection and multi-path effects (= sea clutter), the actual radar detection range is seldom more than 1 kilometre. But in practice this range is often restricted to less than 500 metres. As sufficient area around an offshore wind farm is required to enable adequate bird migration pattern studies, the latter range is considered rather limited.

Low-cost bird radar

TNO has the internal capabilities and other necessary means to develop a relatively low-cost bird radar system, which does meet the above indicated range and detection sensitivity requirements. In addition this radar system, thanks to advanced built-in automation capabilities, requires substantially less man-hours for data processing compared to compatible radar systems. These combined product features qualifies TNO's bird radar system as an ideal tool for continuous bird migration monitoring in the vicinity of offshore wind farms.

The system itself is in essence a combination of maritime radar technology applied in the shipping industry and an FMCW-type radar TNO already applies in other applications. The latter is fitted already with a commercially available DEKODO sea-clutter filter and ROBIN bird detection algorithms. Besides sea-clutter filtering, additional filters for handling wind turbine rotor

reflection issues have been incorporated. Rotor reflection as a phenomenon is highly predictable and the required filtering method as a challenge is therefore rather easy and straightforward to tackle.

TNO developed the original ROBIN system during the past twenty years for the Dutch royal air force (Koninklijke Luchtmacht or KLu) and several European air forces too. Based on radar data obtained from two KLu air control radars, ROBIN software is capable to fully detect and register all bird migration movements (tracks) across Dutch air space. In other words tens of thousands tracks can be followed and visualised simultaneously. The new bird radar system is based on integrating the above-mentioned modules into a single system entity. This system in turn is characterised by a number of distinct features including adequate detection sensitivity, easy-to-operate built-in capabilities, and is finally for clients relatively inexpensive to obtain. The new bird radar system will be extensively tested and validated offshore. These bird migration detection and tracking tests will be conducted in parallel with a 'conventional' state-of-the-art radar system, as well as human observation techniques. The test variables cover a range of different weather conditions, which include bird monitoring during daylight hours and during dusk and darkness at night.

ROBIN Lite design specifications

In the project predefining stage extensive consultation talks have been organised with potential user groups as well as biologists and ornithologists aimed at determining the ROBIN Lite's minimal design specifications:

- 1 Range minimal 4km for a medium-size bird at sea state 2;
- 2 Height range water surface to minimal 2,000m (minimum tracking angle 18°);
- 3 Bird flight path registration in 2D;
- 4 Vertical bird flight height and flux registration in 2D;
- 5 Localised bird flight path and flying height registration in 3D;
- 6 Continuously 365/24/7 operational;
- 7 Remote control en data access;
- 8 Automated bird migration data processing and storage in a dedicated database;
- 9 Automated data transfer to shore;
- 10 Bird migration pattern visualisation;
- 11 Bird species recognition;
- 12 Bird numbers and bird flux registration;
- 13 GIS information application;
- 14 Sea-clutter filtering;
- 15 Additional rain, land and wind turbine rotor reflection filters;
- 16 Low-cost product.

As a main outcome of an extensive customer product demand evaluation TNO decided for a system configuration based upon a combination of two distinct radars. For obtaining relevant 3D bird migration data a horizontal as well as a vertical radar system are required. Horizontal radar thereby records bird migration patterns in the horizontal

plane, while the vertical radar adds height-related data. In total two ROBIN Lite test systems have been developed. One system is located on the roof of the TNO division's The Hague based laboratory, while a second system is available for field testing.

ROBIN Lite horizontal radar

For the horizontal radar system component any state-of-the-art maritime (shipping) radar with X-band and S-band frequencies can be applied. With regard to the radar hardware only minor modifications proved necessary, and an initial choice was made for X-band radar made by Furuno. An X-band frequency is compared to S-band better suited to detect small singing birds, but is as a disadvantage more sensitive for weather-related effects like rain and snow. The range is also slightly shorter compared to S-band.

A bigger challenge proved the system electronics required for generating and processing radar signals into bird-specific information. One of the added difficulties is the fact that bird radar reflection hardly exceeds radar system-related noise. That in turn puts high technical and other demands to data acquisition quality. These demands are of such a high-level that the required system electronics is not available from Commercial Of The Shelf (COTS) market supply sources. TNO therefore engaged a specialised Dutch electronic system developer for supplying the data-acquisition hardware. Due to the generic nature of these system electronics it can as part of ROBIN Lite be connected to Furuno radars as well as comparable radars of competing makes.



ROBIN Lite horizontal radar in testing mode at a wind farm near Dresden, Germany

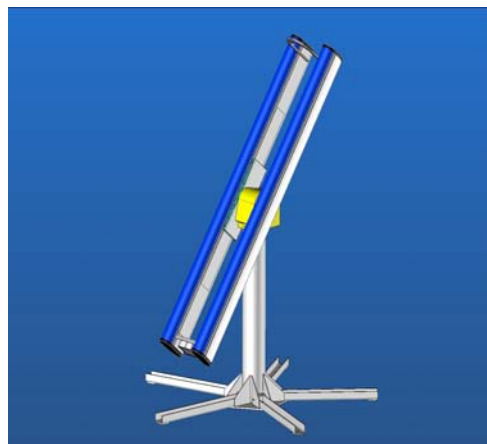
ROBIN Lite vertical radar

Dictated by customer demand for an adjustable height range in a combination with bird species recognition capability the application of a

tilted (horizontal) type shipping radar system proved impossible. The main reason is that shipping radar transmits relatively high-performance pulses (maximum 25kW). However, for bird species recognition a system capability to continuously ‘spot’ a bird is essential. As a key precondition the radar should not rotate too fast in order to continuously keep track of this given bird. However, with modern shipping radar application the latter capability is prohibited for safety reasons. When this specific radar type stops rotating, than also the radar pulse transmission process ceases.

A radar technology that allows the continuous ‘spotting’ of a bird is known as Frequency Modulated Continuous Wave (FMCW) technology. The latter radar type does transmit power continuously instead of by pulses. One main consequence from a radar technology point of view is that two antenna’s are required, one for transmitting and a second for receiving radar signals. And not unimportant an FMCW radar is known as a so-called Solid State system. This implies that the radar energy is not generated anymore as pulses in a radar-magnetron. A key advantage of a Solid State radar system is the much reduced upkeep requirement compared to standard pulse radars.

The trials showed that birds could be detected from about 3 kilometres distance. Initially the FMCW radar transmitting power was 25 mW, but now this capacity is being raised to about 700 mW.



ROBIN Lite vertical radar



Data transfer, data processing and storage

Remote control is an important aspect of the ROBIN Lite system development. This feature has been implemented and field tested during trials at a wind farm near Dresden (Germany) and at the Dutch Woensdrecht

air force base. One of the positive findings was that the system operated continuously for several months, and during that period all data generated were successfully transmitted to TNO's The Hague office. Generic designed data transfer is based upon TCP/IP Wide Area Networks (TCP/IP WAN). That in turn can be achieved with different methods. These have been implemented and tested with the aid of SATCOM, WiFi en ADSL connections. Bird information in the form of bird flight tracks including variables like position, speed, direction, and reflection density needs to be stored in database format. State-of-the-art formats include among others MS-Access, MySQL, and PostgreSQL.



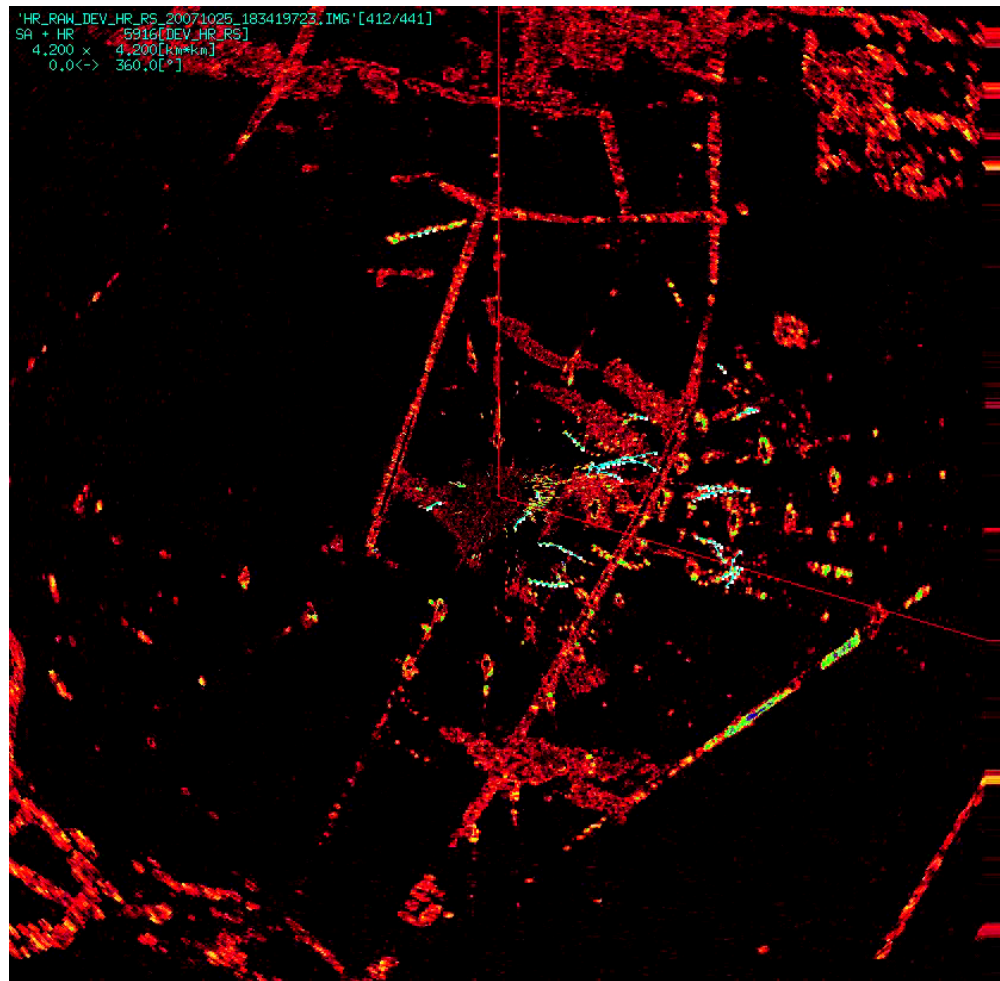
Mobile ROBIN Lite application



Mobile ROBIN Lite application

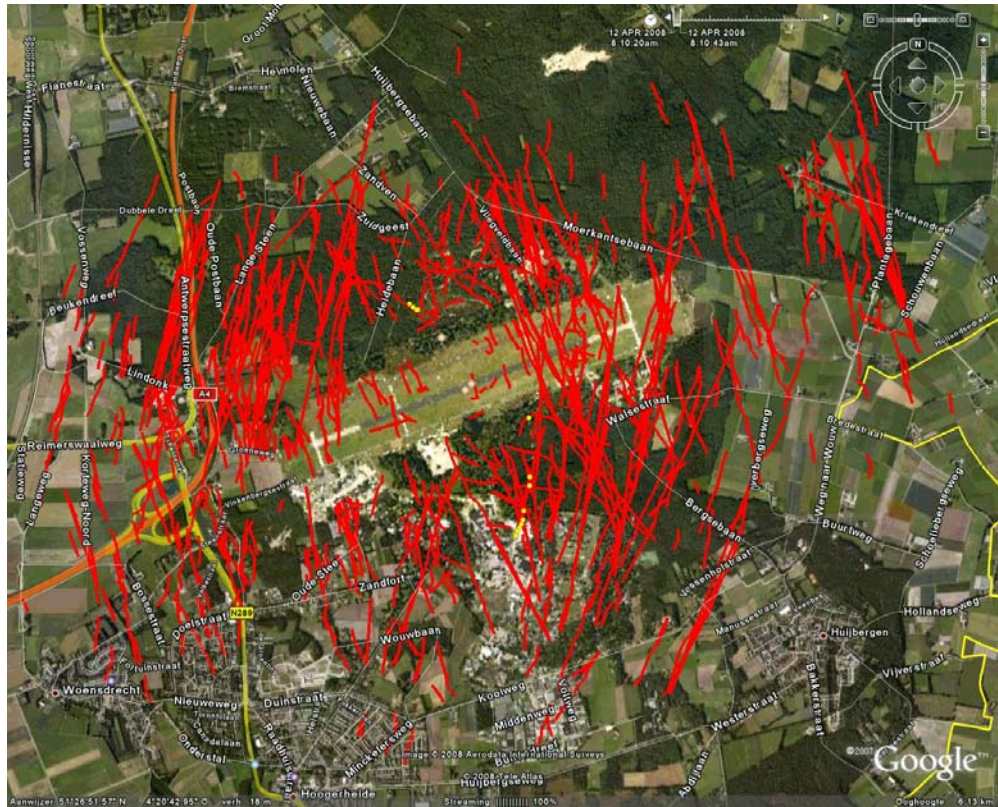
ROBIN Lite data visualisation

Depending on client wishes ROBIN Lite results can be visualised in different manners. One option is to store radar images as unprocessed data, which as an advantage offers the possibility to keep these source data available for (renewed) future processing. A disadvantage is that the data volume increases very fast, which can quickly result in data storage and data transfer bottlenecks. The latter especially occurs when data transmission takes place via a data line with limited bandwidth. This method is therefore only applied for development purposes. Another option is to store radar images as 'streaming video'. That offers the possibility to maintain a capacity to analyse the source data either manually and/or visually, see the radar image example below.



ROBIN Lite radar streaming video image of wind farm near Dresden

The most user-friendly data visualisation method applied today makes use of synthetic data stored in a database. This means in practice that - based on database queries - relevant bird tracks can be pre-selected and visualised with the aid of a GIS (Geographic Information System). The latter method offers by comparison a much-improved understanding of bird movement. A good example offered by bird migration data obtained from Google Earth is for instance represented in the picture below.



Half hour bird migration monitoring image around the Woensdrecht air force base

The ROBIN Lite system finally still needs to be validated by TNO's Dutch project partners Bureau Waardenburg en IMARES.



ROBIN Lite validation trials at Woensdrecht air force base