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RESEARCH ARTICLE

A radar-based efficiency evaluation of obstruction lights controlling at a wind turbine test site

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Abstract

In this study, an obstruction lights controlling (OLC) system based on a Terma SCANTER 5000 radar has been installed at a test centre for large wind turbines. The objective of this study was to evaluate the efficiency of the OLC system and to improve this efficiency by introducing new technological features. Once the first assessment had been carried out, new software with improved tracking functionalities was installed to the radar. With the new software, a second assessment was made to compare the new performance to the old one. To analyse the tracks, geographic information system (GIS) tools have been used. A new MATLAB script was developed to automate the assessment as well as to gather data on the tracks. These data sets were used to improve the system performance by introducing a radar cross section (RCS)/speed filter. The outcome of the study is a filter that can be implemented on the radar system to improve the efficiency of the system and reduce the time that obstruction lights need to be on for by 62.59%, without compromising the integrity of the system.

KEYWORDS

light pollution reduction, obstruction light controlling, radar track classification, radar-based bird identification, wind farm radar surveillance

1 | INTRODUCTION

In the search for more efficient harvesting of wind energy, wind turbines (WTs) are increasingly growing in size. The size of the largest WTs today means that not only can they produce energy at lower wind speeds, but they can also extend into lower airspace. Because of this intrusion into airspace, WTs have to be marked and accompanied by obstruction lights. This is done to warn aircraft of the WTs' presence. The high intensity lights installed on the WTs do, however, present a new challenge, especially when installing wind farms close to populated areas. Local citizens often complain about the lights being too bright and disturbing their everyday (or every night) life. Furthermore, while cleaner air reflects a healthy atmosphere, species diversity and ecological systems are just as important for preserving the balance of natural systems. Since WTs occupy more and more space, ornithologists have expressed their particular concerns relating to the threats which wind energy brings to avian species. As a result of this, and often for no other reason, the commissioning of WT projects can be a long process.

To overcome these challenges, Terma has developed an obstruction lights controlling (OLC) system. This system relies on a Terma radar to monitor the airspace in the vicinity of WTs and if any objects are within a certain distance from the WTs the lights switch on, otherwise they can be kept in the off position. The project was carried out at Østerild (the national test centre for large WT), which is close to Thisted airport. The national test centre was launched in 2012, and users could test seven new WTs, up to an altitude of 250 m. Construction work started in 2011, and a year later, the first test WT was installed. Last year, it was decided that the test centre area would be expanded, adding two more WTs and increasing their height to 330 m.

The radar used in this study was a Terma SCANTER 5202 radar that operates in the X-band (8 to 12.5 GHz). More information on different radar frequency bands can be found in "Introduction to radar."¹ A radar cross section (RCS) was widely used to reflect the signal from a target and back to

the radar. The complex work associated with this analysis is presented in the Nicolaescu and Oroian² paper. Normally, wind farms (WFs) are “blind” areas to radar because of the reflections caused by the rotation of the wind blades. Rashid and Brown³ describe how a typical WT can have an RCS over a large area. Naturally, a grid of WTs will present a large “blind” area, which means that not only will nothing be detected within the WF but the area behind the WF will also be blind to the radar. The Terma SCANTER 5000 Series radar’s ability to detect aircraft within and on the other side of a WF enables one to use the radar to detect aircraft in the vicinity of the WTs and, thus, be able to turn the lights on only when needed.⁴

Monitoring of bird activity at the Østerild WTs test site evaluated the number and species of birds before and after the installation of the WTs. This was done in order to evaluate the influence on birds when large WTs are installed. This monitoring of the birds at Østerild WT test centre was carried out by Danish Centre for Environment and Energy. The monitoring of the effect of the WTs to the birds was carried out three times: a baseline study,⁵ a first year postconstruction monitoring,⁶ and a second year postconstruction monitoring.⁷ These very comprehensive studies give a total overview of the bird species found at the Østerild test site.

One important aspect of this work was to minimize the number of false activations caused by birds. The main method of doing this was to introduce an RCS and a speed filter. In order to set up this filter, a general idea on what size one should expect a bird to have in RCS was needed. Two of the most comprehensive assessments that have been made on the RCS size of birds was carried out by Vaughn⁸ and Huansheng et al⁹ where RCS values were recorded for a very large number of birds. Most birds have a weight between 10 and 1000 g and have a typical RCS size of 1 to 100 cm². The general RCS size of a man is 1 m², a fighter aircraft is 2 to 6 m², and a large commercial aeroplane¹⁰ is approximately 100 m².

In this article, we have assumed the estimated average RCS of a bird to be 10 cm². This value is well below that of a typical jetfighter. However, discussions with radar technicians and experts at Terma revealed that the type of aircraft that is typically hardest to track with the radar system is a glider. As there are several airports that operate glider aircraft near to the test centre in Østerild (ie, Thisted and Morsø airports), the possibility of these entering the vicinity of the WTs is very high. Perotoni and Andrade¹¹ simulated a model of a glider aircraft, and even though the glider has a very low RCS (1.46 m²), this is still considerably higher than what can be expected from birds.

Light pollution is getting a lot more attention in recent years and research has shown that light pollution is influencing both humans and the natural environment. According to Longcore and Rich,¹² there are two types of light pollution: astronomical (which hinders the view of the night sky because of background lighting) and ecological (which influences all living organisms). Ecological light pollution is often described as the fastest growing pollution and might have a huge impact on our lives in the near future. There are several studies linking exposure to artificial light at night with the incidence of cancer and exposure to light pollution could lead to a decrease in pineal melatonin.^{13–17} Specifically, Chepesiuk¹⁸ found a statistically significant correlation between areas with high outdoor artificial light and breast cancer. There is an immediate need to minimize ecological light pollution but no precautions are currently being taken in this direction.

There is also the effect on birds. It has been calculated that bird fatalities can be reduced by between 50% and 71% by removing steady-burning, red obstruction lights.¹⁹ Drewitt and Langston²⁰ suggested that white flashing lights should be used to reduce the number of bird fatalities, since a large numbers of birds collide with illuminated structures. Other studies conclude that birds appear to be attracted to the steady-burning red lights.²¹ As seen from the above studies, there is a lot of interest in reducing bird fatalities. Many WF owners are requesting technology that can detect the birds and prevent them from colliding with the wind towers and blades.

This paper presents a holistic, technical approach aimed at minimizing the impact of obstruction light pollution on humans and the surrounding nature.

2 | METHODOLOGY

During this work, a constant evaluation of the tools being developed was carried out with the aim of updating each iteration, as more knowledge was gained on the subject. This is a common approach in technology-based problems: the engineer builds a prototype and then tests it to see if it has the required functionality (trial and error). This approach has been used in this project because the implementation of the filter required several iterative loops in order to achieve its required functionality. This project required several tasks to be implemented and artefacts were produced (Figure 1). **F1**

Designing a bird filter is a quantitative process as the filter functions on a mathematical basis, leaving no room for researcher bias. However, the thresholds used in the filter (speed and RCS) are currently based on estimations as to what would be reasonable based on the tracks and the literature. The analysis datasets were collected twice a week, which gave a good representation for the test periods.

A warning zone (WZ) was set up around the obstacles (light towers) in Østerild for analysis. This zone ensured that the light turned on before an aircraft entered the 5500-m perimeter surrounding the obstacles. Furthermore, a detection zone (DZ) was created around the WZ. This zone allowed the radar to have full coverage, in order to initiate and maintain a stable track on the aircraft well in advance of it entering the WZ. This zone was not defined as a zone in the radar system but should be considered as being an area where the radar should have a line of sight. The DZ was set at a width of 3700 m. The two different zones are illustrated in Figure 2. **F2**

As long as there are no tracks within the defined WZ, the radar will publish a message of “detection clear.” Should a track enter or emerge in the WZ, the radar will detect it and immediately change the message to “detection on.”

If a track is lost (disappears) within the WZ, then the message changes to “detection uncertain” and the obstruction lights come on, on a timer for 30 minutes. This ensures that a possible aircraft will have the time needed to leave the zone before the lights are turned off. The radar constantly publishes its protocol entries, and these are logged on the computer connected to the radar. When the files are to be downloaded to the

FIGURE 1 Tasks and artefacts of the project

FIGURE 2 A, Detection and warning zones general description and B, DZ and WZ at the Østerild wind turbine test site. DZ, detection zone; WZ, warning zone [Colour figure can be viewed at wileyonlinelibrary.com]

local computer, one must first connect to the gateway computer and use that as a tunnel to connect to the computer at the radar site. With WinSCP, or any other FTP programme, the files can then be downloaded to the local computer.

3 | TRACK ANALYSIS AND DATA COLLECTION

Once the connection to the radar was established and the radar was operational, it started logging all published messages into the following protocol files:

- .SAP11—Surveillance Area Protocol: This protocol stores all the messages published on the current state of the Surveillance Area Target Detection (SATD) protocol.
- .TCP 13—Track Configuration Protocol: This protocol describes the configuration of the AtoNs (all the stationary targets that are marked in the radar system in order for the radar not to initiate a track—for instance a typical AtoN would be a WT).
- .TDP22—Track Data Protocol: This protocol stores all of the tracks made, as detected by the radar. The protocol stores multiple data of the track as seen in the small snippet below. In this analysis, only some of the available data will be used.

An example of the lines of each protocol are presented in Figure 3.

The relevant data for the system was further analysed. However, the following questions were raised and investigated:

- What is the overall efficiency of the system?

760	2017-03-17T14:07:26Z	detection on, cesterild
761	2017-03-17T14:07:28Z	detection on, cesterild .SAP11
762	2017-03-17T14:07:30Z	detection on, cesterild
763	2017-03-17T14:07:31Z	detection uncertain, cesterild

2	atoncreated, aton569616794871n87176543565e, 144.000000, 56.96168, 8.71765
3	atoncreated, aton569653688829n87115596181e, 210.000000, 56.96537, 8.71156 .TCP 13
4	atoncreated, aton569758323765n86824090731e, 203.000000, 56.97583, 8.68241
5	atoncreated, aton570179766639n87327257952e, 93.000000, 57.01798, 8.73273

1	track, 4858, 2017, 3, 17, 13, 55, 8, 542, FA, TARGET, , 63, 6, 7510, 3.50534, 57.011528,
2	track, 5883, 2017, 3, 17, 13, 55, 6, 546, CA, TARGET, , 63, 20, 7524, 3.52879, 57.011986
3	track, 5883, 2017, 3, 17, 13, 55, 8, 547, FA, TARGET, , 63, 42, 7558, 3.52055, 57.011501

1	TRACK	ID	YEAR	MONTH	DAY	HOUR	MINUTE	SECOND	MSEC	STAT	TYPE
2	track	4858	2017	3	17	13	55	8	542	FA	TARGET
3	track	5883	2017	3	17	13	55	6	546	CA	TARGET
4	track	5883	2017	3	17	13	55	8	547	FA	TARGET

FIGURE 3 Snippets of the .SAP11, .TCP13, and .TDP22 protocols (.TDP22 analysed in an excel file) [Colour figure can be viewed at wileyonlinelibrary.com]

- Is the system turning on the lights concurrent to the aircraft entering the WZ? Is there a significant system delay?
- What time of the day is the most active?
- Are there any identified "special" patterns of tracks? For example, are there large flocks of birds at certain places?

3.1 | Track analysis

During the period 17 to 30 March 2017, there were a total of 42 785 measured and published plots. The tracks were categorized, and a visualization tool was used (ArcGIS Track Analyst). This tool visualized the tracks and allowed for the direct import of .csv files (Figure 4). **F4**

The initial analysis needs to categorize the type of tracks and identify the presence of any aircraft. For further assessment of the system's efficiency and integrity, it is important to identify tracks that are definitely aircraft. Furthermore, it should be assessed whether the track is within the WZ perimeter. Commercial aircraft are normally tracked over a long distance, and they fly in angular directions (not changing direction). The speed of some of the tracks is significantly high, and this indicates whether it actually is an aircraft. In Figure 5, such a high speed track is shown. **F5** This track was later identified as Scandinavian Airlines Flight SAS1902. Additionally, all tracks that are identified as an aircraft were verified on flightradar24.com and Planefinder.net.

In Table 1, all of the tracks found are categorized according to the summary of findings. **T1**

There is a lot of bird activity in the area, and there are many tracks caused by this (Figure 6). Because the birds land within the WZ, the track is **F6** lost, and the 30-minute timer (with lights on) is started. This has a serious effect on the overall efficiency of the system.

The next step of the analysis was to verify the (.SAP11) protocol (which describes the state of the WZ). It is possible to verify how much of the time the lights are activated for and if they are only active when there is a track within the WZ perimeter. It is also possible to work out how often a track is lost within the WZ.

FIGURE 4 A, All tracks added to the map and B, analysis of a specific track via ArcGIS Track Analyst [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 5 Track identified as aircraft found at Planefinder.net [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Summary of tracks categorization

Number of tracks within radar coverage	544
Number of tracks in the DZ	175
Number of tracks in the WZ	229
Number of aircraft	103
Number of aircraft in the WZ	16
Number of aircraft in WZ with ADS-B transponder	4
Number of aircraft with ADS-B	49
Total seconds with aircraft in the WZ	1622

Abbreviations: DZ, detection zone; WZ, warning zone.

In order to gain knowledge about the tracks lost within the WZ, the number of “Uncertains” was counted. The total number was 18 975. Normally, a message is published every 2 seconds, so it is easy to calculate the total time that the lights have been turned on due to the system being in an “Uncertain” condition. The result is 37 950 seconds (by multiplying the number of Uncertains by 2).

However, in a fully operational system, a timer would have to be initiated each time an uncertain event occurred (due to the track being lost within the WZ). This timer was set to 30 minutes, thereby allowing a potential aircraft to leave the WZ while the obstruction lights are kept on. This means that the protocol in this analysis does not reflect the actual time that the lights are turned on. In order to evaluate the right time for timeout and also get the number of uncertain (ie, tracks lost within the WZ), the uncertain were evaluated again. This was carried out via the SAP11 protocol, and only individual uncertain were counted this time. The total number of individual uncertain was found to be 198. In order to

FIGURE 6 Bird activity (6500 m south of the radar) (3300 m south of the wind turbines) [Colour figure can be viewed at wileyonlinelibrary.com]

calculate the total, actual time that the system would have kept the lights on because of being in an uncertain state, then the total number of uncertain has to be multiplied by 30 minutes. Therefore, the total time was 356 400 seconds, which is approximately 100 hours of the lights being fully operational, and this was practically 30% of the total time observations were being made (Table 2).

The OLC radar system at the Østerild test centre is only to be activated during the night (from sunset to sunrise). Therefore, it was interesting to see at what times of the day there is most activity and if there are any patterns in this activity for this specific site (Figure 7).

Figure 7 clearly shows that most activity occurs at two specific times of the day. These are (1) from 5:00 to 9:00 in the morning and then (2) from 16:00 to 18:00 in the evening. Sunrise and sunset at Thisted airport was 05:57 (sunrise) and 19:10 (sunset) on 17 March 2017 and 06:21 (sunrise) and 20:39 (sunset) on 30 March 2017. With these times in mind, it is clear that most activity occurs just after sunrise and around sunset. This makes sense because birds are normally most active at these times.

3.2 | New software tool and new protocol implementation

The system was found to be working efficiently in separating birds and aircraft tracks; however, the time with lights on remained high. Two relevant updates were required and actively introduced to the OLC radar application:

TABLE 2 Summary of the preliminary analysis

Total Active Time, s	1 138 152	% of Total
Total time with lights on (uncertain = 3-min timer), s	56 694	4.98
Total time with lights on (uncertain = 30-min timer), s	377 445	33.16
Total time in on state, s	21 045	1.85
Time uncertain (30-min timer), s	356 400	31.31
Number of uncertain (tracks lost within the WZ)	198	
Number of tracks	544	
Number of tracks in the WZ	229	
Number of aircraft	103	
Number of aircraft in the WZ	16	15.50
Total seconds with aircraft in the WZ	1622	

Abbreviation: WZ, warning zone.

FIGURE 7 Illustration of number of tracks per hour of day (red markings for sunrise and sunset) [Colour figure can be viewed at wileyonlinelibrary.com]

- Better possibilities for track categorization via an RCS estimator and improved possibilities for using filters.
- A “static target estimator” that “learns” (via a machine learning approach) what should be classified as static targets in the near environment and, thus, does not initiate tracks on these targets. This should mean that the need for AtoNs is removed.

These two new tools will also make the OLC radar system easier to install at different locations as there will be less need for site-specific configurations of the system. Naturally, with the installation of the new software, a lot of changes were made to the system. One of them was the introduction of a new protocol.

FIGURE 8 Speed and radar cross section (RCS) filter visualization [Colour figure can be viewed at wileyonlinelibrary.com]

- .TDP10—Track Data Protocol with new functionalities:
 - an RCS estimator which makes it possible to estimate the RCS size of a target,
 - “prepared for” track classification. Based on measurements of the targeted track, the system can classify the track with no further processing (ie, as an aircraft or bird).

One of the main changes that were made in order to minimize the number of birds tracked was setting up a filter with two parameters. The new filter that was developed is a combined speed and RCS filter. This means that the filter will only allow the tracks through to the Surveillance Area Target Detection protocol if:

- The speed of the track is above a certain speed threshold (y_1), and the RCS is larger than another threshold (x_1).

FIGURE 9 Summarizing figures for each track [Colour figure can be viewed at wileyonlinelibrary.com]

FIGURE 10 Graph with all tracks plotted by radar cross section (RCS) and speed (m/s). Tracks identified as aircraft are marked red [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 3 Extracted data for each day in the new 14-d period

Date	Total on Time, min	"On" Time, min	"Uncertain" Time, min	Number of "Uncertains"	Number of Tracks
23/5/2017	68.21	7.94	60.26	2	55
24/5/2017	166.33	4.92	158.31	6	56
25/5/2017	38.33	4.85	33.48	2	50
26/5/2017	244.67	36.93	207.73	6	64
27/5/2017	316.44	35.35	281.09	10	107
28/5/2017	187.66	6.45	180.93	6	35
29/5/2017	96.64	8.45	88.18	3	28
30/5/2017	96.30	6.55	89.74	3	30
31/5/2017	211.60	9.36	202.24	7	77
1/6/2017	104.30	7.47	59.94	2	78
2/6/2017	169.27	13.53	149.85	5	55
3/6/2017	163.73	14.00	149.72	5	62
4/6/2017	161.52	7.34	154.17	6	66
5/6/2017	402.92	19.34	383.58	15	178
Total	2359.71	182.48	2199.22	78	941

TABLE 4 Track categorization for the 14-d period using the new software

Date	Tracks in WZ	Number of Aircraft	Number of Aircraft in WZ	Time with Aircraft in WZ, s
23/5/2017	16	1	1	255
24/5/2017	38	3	0	0
25/5/2017	22	12	0	0
26/5/2017	35	21	10	2040
27/5/2017	54	16	2	1124
28/5/2017	23	1	0	0
29/5/2017	16	8	3	376
30/5/2017	10	5	1	137
31/5/2017	28	4	1	278
1/6/2017	18	13	0	0
2/6/2017	15	8	3	701
3/6/2017	15	6	1	322
4/6/2017	22	5	0	0
5/6/2017	41	14	4	392
Total	353	117	26	5625

TABLE 5 Summary of the first comparative analysis

		% of Total	% Compared With Old Software
Total active time, s	1 209 600		5.91
Total time with lights on (uncertain = 30-min timer), s	141 582	11.70	-62.49
Total time in on state, s	10 949	0.91	-47.97
Time uncertain (30-min timer), s	131 953	10.91	-62.49
Number of uncertainties (tracks lost within the WZ)	78		-60.60
Number of tracks	941		72.98
Number of tracks in warning zone	353	37.51	54.15
Number of aircraft	117		13.59
Number of aircraft in warning zone	26	22.22	62.50
Total seconds with aircraft in warning zone, s	5625	0.47	246.79

Abbreviation: WZ, warning zone.

- OR
- The speed of the track is above another significantly higher speed threshold (y_2). The speed threshold y_2 is introduced to turn on lights in case a fast flying aircraft enters the WZ. This fast flying aircraft could well be a fighter jet with a low RCS value; thus, the lights should turn on immediately even though the RCS is below the threshold.

Figure 8 visualizes how the filter parameters determine which tracks are published and which tracks that are sorted out. Figure 8 illustrates the importance of the set points (object speed and RCS) in order to record valid data only. Any tracks within the blue area will not be published.

4 | RESULTS AND DISCUSSION

For the analysis, MATLAB was chosen as a tool to run the tests because it can script most of the tasks. It was seen that the number of analyses was also reduced as some of them were not needed. The protocol .SAP11 log file was inserted in MATLAB and divided into the four categories: (a) clear, (b) uncertain, (c) on, and (d) other (error/not operational). The total time for each of the categories was calculated and then outputted as a percentage of the on/off time. From the data that has been imported into the function described already, some analysis was carried out on the tracks to identify and sort them. This is done in the functions: (a) analyse periods with detection on, (b) sort according to MESSAGE-ID, and (c) remove samples with LACKS $\approx$ 0.

After these analyses were processed, a summary for each track was prepared. In this way, for every single incident, a figure from MATLAB is produced for a given track (Figure 9).

For identifying the aircraft, a new MATLAB script called "reducedTrackData_dBsig" was developed. This tool has several different functionalities, and one of these is producing a graph plotting the RCS and speed of all of the tracks.

The RCS used is a relative RCS in the interval from 0 to 1. This is the format that the radar outputs the measured RCS in; however, the actual RCS value can be calculated from this relative number.

When a track is identified as an aircraft in Google Earth, the ID of that track can be put into the function, and it will then be marked in red (Figure 10).

From the values in Figure 10, it is immediately evident that the tracks can be grouped, for example, there are a lot of tracks in the lower left hand corner but no aircraft, therefore, the first thresholds (y_1 and x_1) could well be placed so that they encapsulate these tracks. In this way, all of the tracks that are small in RCS and slow flying will be sorted out. In the above, figure x_1 could be placed around 0.5, which would sort out all aircraft. If y_1 and y_2 are then placed in the 20 to 60 m/s range, all tracks not being aircraft would be filtered away.

With the filter enabled, and the new MATLAB tools for analysing the tracks made available, a new 14-day period was selected. This time, the test period was from 23 May 2017 at 10:00 until 6 June 2017 at 10:00. The data from the individual dates had to be extracted using the MATLAB tools described above (Table 3).

The output of the analysis for this new period of time is presented in Table 4.

Based on the findings presented in Table 5, it is clear that, although a lot more tracks were found and more time was spent in the WZ, the total, overall time in the "On" state was reduced by almost 50%. The total time of uncertainties was reduced, and the tracks lost were also reduced, by approximately 60%.

5 | CONCLUSIONS

The overall conclusion for this study is that the research carried out has improved several aspects of the OLC system and the processes associated with it. The first improvement is in the performance of the radar system. It was seen that even though the total time for the second test period (with the new software and filter) was longer and almost 75% more tracks were detected, the overall efficiency of the system was improved. The number of "Uncertains" (tracks lost within the perimeter of the WZ) have been decreased by 62.49%.

Furthermore, tools for analysing and categorizing the tracks and improving the performance of the system have been developed. These tools have greatly reduced the time needed for the analysis. This will be valuable for radar systems worldwide as designers need to periodically report on their systems' performance.

These tools also allow for data gathering of the detected tracks. These data will be used to optimize specific systems, and the proposed methodology can be followed for all future applications, focusing on OLC aimed at minimizing light pollution.

The OLC business is a relatively new market, in general. Few OLC radars are operational at the time of writing, but the market is evolving at a fast pace. The current work gave a comprehensive analysis of tracks in general, including the tools to work on further in order to increase the efficiency of such systems. The work regarding filtering could be implemented in other areas as well. The current methodology could be implemented in bird collision avoidance systems, by recognizing and deterring avian species around turbines and buildings as well as other tall structures. Not only does this technology have promising potential in helping to conserve bird populations but there are also implications for cost reduction (eg, to WF manufacturers and other stakeholders).

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CONFLICT OF INTEREST

The first author, Lasse Due Jørgensen, is a paid employee of TERMA A/S. The other two authors declare no conflict of interest.

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