Detection and Tracking of Aircraft over Wind Farms using SCANTER 4002 with Embedded Tracker 2


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Abstract

Test results of aircraft detection and tracking over large offshore wind farms show that a track can be maintained on a light manoeuvring aircraft as well as general aviation aircraft using an off-the-shelf radar solution. The optimum strategy of mitigating the deteriorating effects of closely spaced wind turbines on air surveillance is shown to depend on the characteristics of the wind farm, in particular the density of the wind turbines.

1 Introduction

The emerging issues for maintaining coverage of air targets close to and above wind farms can be addressed from different viewpoints. Most papers address the possible problems regarding air coverage at wind farms. This paper describes the obtained test results using an ‘off the shelf solution’ at two different test sites. The radar transceiver and tracker used on both test sites will first be presented. This is followed by a description of a test involving a controlled, small, fixed wing aircraft manoeuvring over the two offshore wind farms Horns Rev I and II. We proceed by discussing various options with regard to the radar video used as input to the tracker. Results from the Horns Rev tests are then presented. Another test site at Copenhagen Airport is described, where the setup is used as a Terminal Approach Radar demonstrating also tracking of air targets passing over Lillgrund, a nearby offshore wind farm. Here tracking is done on radar video where individual wind turbines have been blanked out. We present results on how the blanking affects the target plot probability of detection, track loss probabilities accumulated from more than 200 air targets of opportunity passing over the wind farm over a period of six days.

The requirements for inter-turbine detectability and the obtained specification of SCANTER 4002 are discussed in detail in [6]. The requirements for inter-turbine detectability relate to:

- Instantaneous linear dynamic range
- Adaptive sensitivity control
- Pulse compression range side lobes
- Azimuth antenna side lobes
- MTI/MTD suppression of clutter between turbines

To summarize, the stated requirements in [6] are met very well by SCANTER 4002.

2 Radar configuration

The radar set-up includes a SCANTER 4002 and a 15’ Large Aperture Antenna System [7], both produced by Terma in Denmark. The antenna has a $\csc^2$ elevation pattern, circular polarization, a gain of 39 dB, and a 3 dB azimuth beam width of 0.57°. SCANTER 4002 is the latest version of the off-the-shelf product series of SCANTER 4000, now operating worldwide. The SCANTER 4002 radar sensor is an X-band, 2D, fully coherent pulse compression radar providing both enhanced Moving Target Indication (MTI) and Normal radar (Non-MTI) video simultaneously. This enables a high level of situational awareness and support multiple concurrent operational needs e.g. air surveillance, helicopter control, surface surveillance and Search and Rescue. No secondary surveillance radars (SSR) were used during the tests.

The SCANTER 4002 generates both network video and plot/tracks to be overlayed on the video. Two types of video output are generated in parallel: Processed air targets video and Processed surface target video. Both video channels are based on combined MTI and Normal radar (Non-MTI) video simultaneously. This enables a high level of situational awareness and support multiple concurrent operational needs e.g. air surveillance, helicopter control, surface surveillance and Search and Rescue. No secondary surveillance radars (SSR) were used during the tests.

The SCANTER 4002 generates both network video and plot/tracks to be overlayed on the video. Two types of video output are generated in parallel: Processed air targets video and Processed surface target video. Both video channels are based on combined MTI and Normal radar video, but the post-processing is configured differently, optimized for detection of the different target types. As a consequence, the processed air targets video can also include small distinctive targets that usually are present in the normal radar video only. A full resolution attenuation map can be included in the processing. The map blanks each video cell individually if applied and can be set to include stationary targets as wind turbines.

The network radar video is processed by the Embedded Tracker 2 (ET2), see Fig. 1. The ET2 is a knowledge-based [3], auto-adaptive, probabilistic radar tracker, which integrates with most of the SCANTER family of radar sensors. The ET2 is developed by Terma and has been available on the market since June 2012.
In the ET2, network radar video is first passed through a plot extractor, which identifies areas of connected radar cells over a given video threshold. The plot extractor calculates a set of properties for each plot: The plot centre and plot centre positional covariance in slant range and bearing, the observation time, the maximum intensity of the video level of radar cells in the plot as well as other features related to the plot shape and size. Plots may be due to targets, clutter or noise.

![Figure 1: System diagram of the ET2](image)

Extracted plots are sent to a plot publisher and a clutter density estimator. The plot publisher publishes plots to the outside world via a network port. The clutter density estimator uses incoming plots to estimate the density of plots in range, bearing and intensity and augments this density as an attribute to each plot, which are then sent to the core tracker application (blue boxes in Fig. 1) ordered by observation time.

The core tracker consists of three interacting components; a data associator, an estimator and a track pool. The data associator assigns incoming plots with tracks predicted to the observation time using the estimator. On assignment, the estimator updates the target state vector with the assigned plot. A track pool maintains the state of each track (tentative, confirmed, terminated).

The estimator component is composed of three independent estimators: An Interacting Multiple Models (IMM) estimator [1] for the target kinematics, a knowledge-based [3] estimator for target features, and a sequential Bayesian probability of detection estimator [4]. The IMM maintains an estimate of a target state vector and covariance matrix containing the target position, velocity and turn rate in the horizontal plane. The maximum video level in a plot is used by the feature estimator to find the plot intensity probability conditioned the maximum video level found in the most recent plot associated with a target. The probability of detection estimate is used by the track pool component to terminate a track if it drops below a configurable threshold. The memory of the probability of detection estimator is configured in terms of a decay time and distance, which takes into account the temporal and spatial variance in the detection probability of a target.

On reception of each plot, the data associator identifies possible plot-track associations. The optimal plot-track association pairs are found using likelihood based 2D-assignment including both a kinematic and a feature term [2]. The assigned tracks update their estimators with the new plot and the track pool promotes or terminates tracks and sends the results to the track publisher. Unused plots are added to the pool of tentative tracks [3] and used in the next scan as track candidates.

Finally, the plot publisher has the responsibility to publish tracks to one or more tracker clients on a network connection. The published tracks form a subset of the confirmed tracks from the core tracker, which fulfil certain publication criteria. For instance, the track publisher may suppress the publication of tracks, which has never moved above a certain speed over ground with statistical significance, to suppress static or slow targets (wind turbines, masts, ships, birds, etc.).

The ET2 can maintain 1000 confirmed tracks while running on a modest hardware platform (a dual core 1.6 GHz PC platform). It automatically adapts its capacity to the available hardware resources.

### 3 Horns Rev Tests

![Figure 2: Overview of the Horn Rev/Blåvandshuk test site](image)

To test the ability of the described system to detect and track aircraft in the vicinity of large wind farms, a test was conducted at a test site located at 55°33.229’N 8°5.5446’E near Blåvandshuk on the West coast of Jutland, Denmark, see Fig. 2. At the test site, the antenna system was installed at a
height of 12 m ASL with direct visibility to the off-shore wind farms Horns Rev I (80 wind turbines, 70 m hub height, 80 m rotor diameter, 3-4 turbines/km²) and Horns Rev II (91 wind turbines, 68 m hub height, 93 m rotor diameter, 3-4 turbines/km²). To enable later offline analysis, data were recorded at three different points in the signal processing: Unprocessed transceiver data, radar video, and screen dumps from the PPI used. The ET2 was not available at the time of the tests, and the tracking results presented in this paper have been obtained by replaying some of those data after the actual test. The radar antenna was operated at 15 RPM during the tests.

The primary controlled test target was a light aircraft, a Grumman GA-7 with a wingspan of 11.23 m. This aircraft has been used at several factory acceptance tests of SCANTER 4000 products where its radar cross section has been measured to be between 1 and 4 m² depending of the aspect angle.

The controlled aircraft was commanded to pass the two wind farms in a variety of different directions, heights, speeds, and weather conditions. The test was scheduled to take place over a number of days to have different weather conditions. The results presented here are from the first test day, March 29, 2011, with wind from west 5-10 m/s, no precipitation, and the GA-7 flying at an altitude of 5000 ft.

The wind turbines are excluded from the CFAR processing by individual masking. This is required to avoid desensitization in the vicinity of the wind turbines. The result of a successful masking is shown in Figure 3, where a special option on the radar has been enabled, allowing the receiver noise floor to be seen. The noise floor is flat between the turbines and at the same level as outside the wind farm, showing that the CFAR processing does not introduce desensitization in the area of the wind farm. The high azimuth resolution offered by X-Band combined with the 60 dB Peak Side-Lobe Ratio of SCANTER 4002 facilitates the ability to resolve air targets from individual wind turbines.

Figure 3: Non-thresholded radar video over a section of Horns Rev 2.

3 Video Considerations

In aircraft surveillance applications, the static wind turbine targets are of little interest in the control systems fusing track data from different sensor systems. To clean up the published tracks a target speed filter is applied in the track publisher,
which only allows the publishing of tracks, which has had an estimated speed over ground exceeding 25 m/s in five consecutive scans.

In Fig. 5 is shown how the publication filter completely removes all static tracks. It is crucial to understand that the static targets are still being tracked internally in the tracker, they are just not published.

5 Horns Rev Test Results

In Fig. 5, the target again moves over Horns Rev 2 following the turn in Fig. 4. Only this time, the aircraft makes a 40° turn while passing the wind farm, changing its course over ground from 100° to 140°. It is a challenge to maintain a track on the target under these conditions. Approximately one third of the target plots coalesce with the wind turbine plots, which associate with the static wind turbine tracks. This leads to lacks on the aircraft track. In this case, it experiences two such consecutive lacks right when the targets begins its manoeuvre, see red circles in Fig. 6. This is followed by a successful update with an inter-turbine target plot (green circle), which corrects the course and allows the track to be maintained in the scans to follow.

6 Copenhagen Airport Tests

To test the ability to track a wide variety of aircraft over wind farms and also the ability for the SCANTER 4002 to operate as a Terminal Approach Radar (TAR), a test site was setup in Copenhagen Airport at the position 55°37.114’N 12°38.051’E, next to Tower 1 in May 2012. The Horn Rev radar transceiver and antenna system was used, only this time, the radar antenna was installed on top of a 24 m mast, giving an antenna height of approximately 30 m ASL, which is the same height as the primary radar in the airport. Copenhagen Airport is the busiest airport in Scandinavia, with dense air traffic. Moreover, it is located close to several large offshore wind farms, of which the largest is Lillgrund Wind Farm, (48 wind turbines, 65 m hub height, 93 m rotor diameter, 10 turbines/km²) located 15 km to the SE of the test location. Due to size constraints in this region, the wind farm layout is dense, with an inter-turbine distance of 300-350 m. The density of wind turbines in Lillgrund is thus approximately 3-4 times larger than for Horn Rev I and II.

The non-thresholded video over Lillgrund is shown to the left in Fig. 8. The noise threshold is still constant in between the turbines indicating that there is no loss of sensitivity.

However, for the Lillgrund case it turns out to be hard to maintain an internal static track for each wind turbine. From scan to scan, they often coalesce with neighbouring turbine plots. Moreover, the large density of plots is detected as a very large clutter density in the area by the clutter density estimator in the ET2. This makes track initialization and maintenance on the static wind turbines slow and a track
cannot reliably be maintained on each turbine. This leads to track seduction for aircraft passing over the wind farm, as an air track may associate with a wind turbine plot instead of an air target plot, especially if the air target manoeuvres.

Figure 8: Non-thresholded radar video of Lillgrund wind farm without (left) and with (right) individual wind turbines masked out. To the right is also seen a track maintained on an air target passing over the wind farm.

For the Copenhagen Airport tests we have therefore chosen to mask out the wind turbines in the video, see Fig. 8 (right). If the masking is done accurately, overlapping target plots will often spill over into the unmasked regions and lead to a clipped plot, which can still be used to associate with a an air target track. Moreover, the static wind turbine plots do not add to the estimated clutter density easing track initialization and maintenance in the vicinity of the wind farm. An example is shown in Fig. 8 (right), where an air target passes over four turbines in three scans without a track lack.

A snapshot of the track situation picture is shown in Figure 9 using the same track publication criteria as for the Horns Rev Tests. Two air targets with IDs 5708 and 6263 are approaching with speed over grounds of 177 and 96 knots, respectively demonstrating the capability of the system to work as a TAR. Another track with ID 7014 has just taken off from the airport and is approaching the Eastern edge of the masked out Lillgrund wind farm at a speed over ground of 257 knots. The trail of a fourth track passing East of Lillgrund is also seen. It should be noted, that since no SSR radar information was used, the track ID is a unique number designated to the target by the tracker, and not the squawk code used by the aircraft transponder.

Only a small fraction of all aircraft pass over the wind farm. By logging all track data over a period of days, tracks can be identified in post-processing which has had one or more track reports with positions within the wind farm. An example of this is seen in Fig. 10 from tracks accumulated over six hours. It is seen that incoming tracks (black) have a probability of detection (filled symbols indicate successful plot-track associations) close to unity. As the tracks pass over the wind farm (blue), the tracks are maintained, but the probability of detection drops due to track lacks (hollow symbols). After having passed the wind farm (green), the probability of detection goes up again to near unity. The track trajectories are smooth, and none of the tracks are seduced. A single track lacks on its way towards the wind farm and is then lost. This could be a false track.

Tracks can be maintained quite easily over the wind farm albeit the probability of detection goes down, because most commercial aircraft passing over, only manoeuvres very slightly. From track data accumulated over six days from June 30 to July 5, 2012 it was found that 218 air tracks had one or more track reports (updating or coasting) over the wind farm. Of these, 17 tracks (8%) were lost. For inbound tracks, the probability of plot detection is 96% in a sector with a bearing 130°-150° and range 10-20 km. Inside the wind farm it drops to 58% due to the masked out turbines.

7 Discussion

By including the static wind turbines in the internal tracking process we can maintain a track on a manoeuvring light aircraft passing over Horns Rev I and II wind farms in different directions. Maintaining internal tracks imposes an extra load on the tracker, but this is easily accommodated within the processing capabilities of the ET2. Although target plots occasionally coalesce with wind turbine plots, it is possible to maintain the track on the target due to the high resolution of the radar sensor without using SSR data.

For wind farms with a smaller inter-turbine distance the best tracking performance is achieved by masking out the wind turbines in the radar video. Although the masking reduces the probability of detection from 96% to 58%, it is still possible to maintain track on a large majority (92%) of all aircraft passing over the wind farm.
Figure 10: Track history for all 21 air tracks passing over Lillgrund wind farm during a 12 hour period on June 30, 2012. Filled: update, hollow: lack, black: inbound, blue: over, green: out bounds.

8 Conclusion

The results presented in this paper demonstrates that it is possible to detect and maintain track on a light aircraft manoeuvring over large offshore wind farms using a SCANTER 4002 radar with an ET2 tracker. It is furthermore shown that commercial aircraft passing over a large offshore wind farm with inter-turbine distances down to 300 m can be tracked and maintained with a probability of 92%. For wind farms with an inter-turbine distance of 500 m or larger, the best results are found by including the turbine video in the tracking process and maintain internal (not published) tracks on these. For wind farms with a larger density of wind turbines, masking out the wind turbine video can give better results.

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References


