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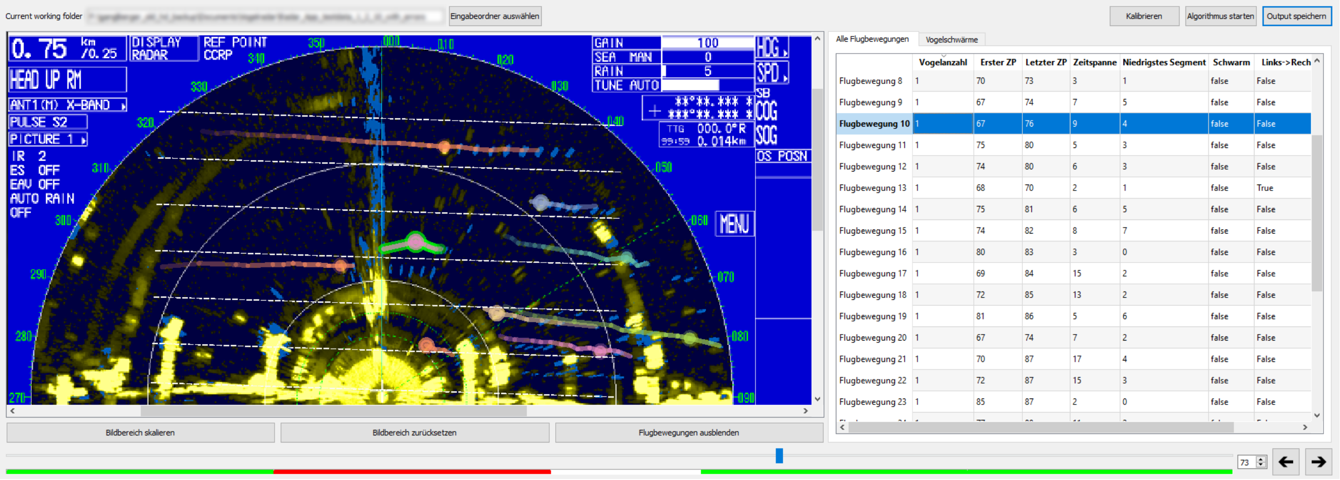
Short Paper

Feasibility Study For Automatic Bird Tracking and Visualization from Time-Dependent Marine Radar Imagery

Florian Ganglberger[1] and Katja Bühler[1]
[1]VRVIS Research Center



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Flugbewegung 13	1	68	70	2	1	false	True
Flugbewegung 14	1	75	81	6	5	false	False
Flugbewegung 15	1	74	82	8	7	false	False
Flugbewegung 16	1	80	83	3	0	false	False
Flugbewegung 17	1	69	84	15	2	false	False
Flugbewegung 18	1	72	85	13	2	false	False
Flugbewegung 19	1	81	86	5	6	false	False
Flugbewegung 20	1	67	74	7	2	false	False
Flugbewegung 21	1	70	87	17	4	false	False
Flugbewegung 22	1	72	87	15	3	false	False
Flugbewegung 23	1	85	87	2	0	false	False

Figure 1: *A tool for automatic bird tracking and visualization from radar imagery. The left view shows a radar image taken in vertical recording mode with bird tracks as colored lines, and dots depicting the birds' current position. White dotted lines indicate the height segments (100 m each) above the radar. The right view shows quantitative information about the detected bird tracks. The selected track ("Flugbewegung 10") is highlighted by a green halo in the left view. The bottom panel can be used to navigate through the images chronologically. The colored bar encodes which images were used (green), which were omitted by the user (red), and which could not be used due to errors (white).*

Abstract

In recent years, radar technology has increasingly been used for the monitoring of bird migration. Marine radars are often utilized for this purpose because of their wide accessibility, range, and resolution. They allow the tracking of birds even at night—when most bird migration takes place—over extended periods of time. This creates a wealth of radar images, for which manual annotation of bird tracks is not feasible.

We propose a tool for automatic bird tracking and visualization from marine radar imagery. For this purpose, we developed a bird tracking algorithm for vertically recorded radar images that is able to extract quantitative parameters including flight direction, height, and duration. The results can be qualitatively verified by a visualization design that enables domain experts the time-dependent visualization of bird tracks. Furthermore, it allows a preprocessing of radar images taken by screen capturing for device independence. Our tool was used in an ornithological monitoring study to analyze over 200.000 vertically recorded radar images taken in multiple observation periods and locations.

1. Introduction

Infrastructure projects in the countryside, such as high-voltage lines and wind power plants often require ornithological monitoring to foresee their effects on the local wildlife. Classical methods include the collection of collision victims (i.e. birds collided with the power lines/plants) and the visual recording of bird migration during daylight [RAT15]. The usage of radar technology enables tracking of birds at high altitudes even at night—when most bird migration takes place [NDS*18]. Performed over extended periods of time (i.e. weeks to months), this monitoring can create vast data resources. As manual annotation is often infeasible due to limited time and personnel resources, automated data analysis is needed.

For tracking bird migration, a variety of different radar types is used: Weather radars that enable continent wide forecasting of bird migration [MFH*11, DLS*11, VH18], marine radars to detect multiple individual birds in the range of several kilometers

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[DBE*13], tracking radars to track and classify single individual birds [ZSvL*08], and specialized bird scan radars that combine the advantages of both marine and tracking radars [swi19]. A detailed validation of individual radar systems for bird monitoring was published by Nilsson et al. [NDS*18].

In this paper, we focus on marine radar systems since their operational range/resolution and their wide accessibility are ideal for studying the effect of man-made structures on bird migration [DBE*13]. To detect flying objects, such as birds, insects, or bats, above an area, marine radars can be used to generate spatial radar data in two different operational modes: Azumuth-Scanning, sampling the horizontal distribution (view from above, i.e. where the objects are located around the radar) and Elevation-scanning to sample the vertical distribution above the radar (view from the front, i.e. to measure position and height of the objects) [SCK14]. The capturing volume of these modes can be seen in Figure 2. In these images, the radar echoes of flying objects are visualized as *blips* that change their position over time. By tracking an object, its velocity, flight height (in the vertical distribution), and direction (horizontal/vertical distribution) can be determined [SCK14]. This information can then be used to derive their nature (i.e. if it is a bird or not) and frequency (by counting distinct moving objects), and as a consequence, how they change in different observation periods.

The underlying principles of *blip* detection algorithms have been described by Stephanian et al. [SCK14], who split the process into consecutive tasks, including background thesholding, blob detection (i.e. which pixel belong to the same object), and blob filtering (i.e. which blobs are artifacts/noise). The remaining blobs then represent *blips*, that can be tracked over time to distinguish individual moving objects. Similar techniques have been used for detection in weather radar data [HK08, DLS*11]. Along with proprietary, not published tracking algorithms (e.g. like it is used in [DBE*13]) provided with the radar systems, a common tool for *blip* detection and tracking is radR [TBM*10]. radR can be used to analyze spatial radar images in R [R D19] for biological targets [Gum13,NDS*18]. It enables data preprocessing (decluttering, filtering), *blip* detection, and tracking (nearest neighbor or multiframe correspondence models). This can be performed either script-based for batch processing or visualized in a graphical user interface.

Although radR represents a versatile tool for studying bird migration with radar imagery, it tends to overestimate the number of birds with increasing track duration [NDS*18] (i.e. the algorithm loses track of a bird and counts them as distinct individuals). This is especially crucial for monitoring over several weeks/months, where this error accumulates. For extensive studies with multiple observation periods, radR offers a script-based batch processing to avoid repetitive tasks in the GUI. This might not be easily performed by non-experts in statistics/computer science. Furthermore, it lacks visualization of individual tracks so they can be checked by a domain expert, which would increase the overall confidence in the result.

We meet these shortcomings by performing a feasibility study about automatic bird tracking and visualization from marine radar imagery that is suitable for longitudinal studies of bird migration by ornithologists. In this study, we sought to create a tool to analyze over 200.000 vertically-recorded radar images taken in multiple observation periods and locations in Lower Austria by our project partners *coopNATURA* [coo19]. This tool allows the usage of radar images taken by screen capturing, parameter calibration in a graphical batch mode, automatic tracking of individual birds and swarms, the extraction of quantitative parameters (i.e. flight direction/height/duration). Furthermore, we developed a design scheme to verify the tracking algorithm's performance qualitatively. Hence, we consider the main contribution of this study to be

- a device independent algorithm for automatic detection of individual bird tracks and swarms
- a visualization scheme for bird migration in time-dependent radar imagery

2. Data

In this study, we collaborated with ornithologists who created over 200.000 vertically-recorded radar images for a longitudinal study of bird migration (as seen in Figure 2b). For this purpose, they used a *Furuno Marine Radar Far 2117* which completes a rotation every 2.5 seconds. They recorded the radar images with screen capturing of the radar's monitoring application (Figure 3) with the same frequency for maximum temporal resolution. Therefore, it is possible that during recording, the monitoring window can be moved, obstructed by other windows, the radar coverage area is changed, or the software loses its connection to the radar for several seconds. An image shows a space above and besides the radar. Yellow *blips* indicate echos of the radar signal, for example from wind power plants (red-dashed circles), terrain, atmospheric phenomenons such as clouds, or flying objects. Moving objects (red dashed and solid rectangles) are followed by blue *echo trails* that are generated by the radar software and were originally used to indicate the course of ships. They show the position of yellow *blips* in previous images. Furthermore, the size of small objects is enhanced, so ships could see potential obstacles. Hence, birds (red solid rectangles) and swarms (multiple birds, red dashed rectangles) appear larger than their actual size. The area below the horizontal axis represents the ground floor and consists of noise and indirect echos.

3. Requirements

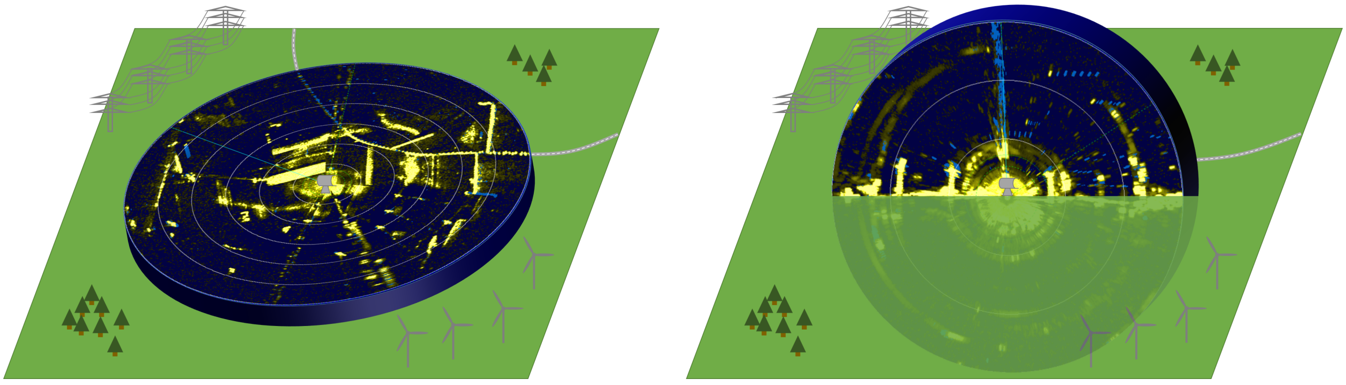
Based on the informal interviews with the domain experts, personal, and e-mail correspondance, we identified the following requirements for a tool for automatic bird tracking.

R1) Batch image calibration: The screenshots of the radar software need to be cropped, faulty images need to be removed.

R2) Bird/swarm tracking: To gather information about individual birds, it is necessary to determine which blips are parts of bird/swarm tracks

R3) Qualitative evaluation of the results: To gain confidence in the analysis, visual verification of the result needs to be possible.

R4) Acquisition of quantitative information: How many birds have been detected and what are their flight heights, times and directions?



(a) **(b)**

Figure 2: *(a) Marine radar in horizontal mode, sampling objects in a range of 0.75 kilometers around the radar. (b) Marine radar in vertical mode, sampling objects 0.75 kilometers above and besides the radar. In vertical mode, parts of the cylindrical capturing volume of the radar is underground and can be ignored (indicated by transparency).*

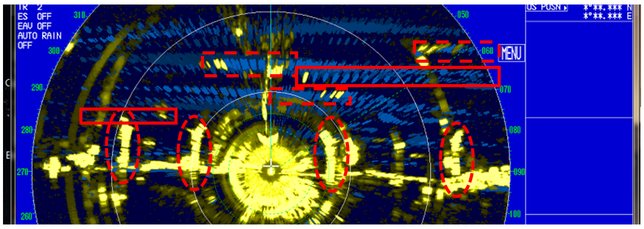


Figure 3: *Screen capturing of the radar monitoring window. Yellow blips indicate radar echos, blue blips are echo trails showing blips of previous recordings. Red dashed circles show wind power plants, red solid rectangles birds and their trails, and red dashed rectangles swarms (multiple birds).*

4. Tracking Algorithm

We developed a tracking algorithm for birds and swarms (R2) radar imagery based on three basic principles of bird tracks that we worked out with domain experts.

- *blips* of bird tracks need to be close together (birds have a certain speed)
- birds do not change their direction abruptly
- a bird needs to be detected in at least 3 sequential images (one or two could be random *blips*)

Therefore, we created a *track score* to rank a track b (sequential set of $n \geq 3$ *blips*) based on the angles of the flight vectors (2D vectors between the *blip* centers) and their length (distance between *blips*):

$$trackscore(b) = \frac{\sum_{i=1}^{n-2} 180 - angle(b_i, b_{i+1}, b_{i+2})}{n-2} \cdot$$
$$\frac{\sum_{i=1}^{n-2} (180 - angle(b_i, b_{i+1}, b_{i+2})) \cdot dist(b_i, b_{i+1}) \cdot dist(b_{i+1}, b_{i+2})}{n-2}$$

The first part of the equation has the effect, that straight flying birds get a lower (better) score, while the second part rewards close *blips* in flight direction. This allows also for larger distances as long as a bird does not change its flight path, e.g. when a *blip* is missing/obfuscated in an image.

The tracks with the best track scores are then computed in Algorithm 1. Here, the algorithm chronologically iterates through the radar images. *Blips* are detected by computing the difference between the green RGB channel (yellow radar echoes) of one image at the timepoint t to the blue RGB channel of the next image at $t+1$ (blue *echo trails*). This leaves only blobs of moving objects, which represent the *blips* of birds. Then, tracks of all *blips* from $t-2$ to t with the best track scores are created, and afterwards merged with already detected tracks. Since this takes only recent tracks into account, the computational cost grows only linearly with the amount of images.

After track detection, tracks can be automatically identified as swarms by their mean *blip* size (*blips* are overlapping), or if two tracks run closely in parallel (*blips* of two tracks have only a certain maximum distance to each other).

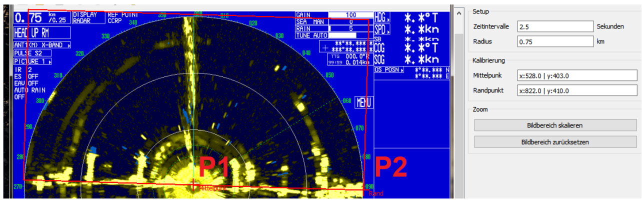
5. User Interface Design

5.1. User-based Data Preprocessing

Users want to analyze large quantities of data with as few interactions as possible. As described in Section 2, the screenshots containing the radar imagery need to be cropped, and faulty images removed (R1). Therefore, we split the images into stacks—sets of sequential images without changes beyond bird movements. We detect them via image subtraction, i.e. if two images exhibit a difference above a certain threshold. As a consequence, the actual radar monitoring area of an image needs to be cropped only for one image per stack. For this, only two positions are required: the center of the radar monitoring area (P1), and a point along the edge (P2) that spans a line parallel to the ground (Figure 4). Additional parameters including radar range (distance between P1 and P2 in kilometers) and time-resolution (time between images in seconds) set the bird tracks into the correct spatio-temporal context (e.g. flight height/distance in meters instead of pixels) (R4). For an example see Supplementary Video 1.

```
Data: $I$, a set of chronologically sorted radar images,
      $maxTrackscore$, the maximum allowed score for tracks, and
      $maxDist$, the allowed blip distance in newly created tracks
Result: A set of bird tracks $B$
$B = \{\}$;                                  // set of bird tracks
$P = \{\}$;                         // set of potential bird tracks
for point in time $t \in 1$ to length(I) do
    add all blips in $I_t$ as single-blip tracks to $P$;
    // Create tracks from single-blips
    repeat
        triples = all combinations of 3 sequential single-blip
          tracks of $P$ where the blip distance<maxDist;
        merge triple with best track score in $P$;
    until no tracks can be merged (trackscores>maxTrackscore);
    // Merge two longer tracks or append
       single-blip to track
    repeat
        concatenatedTracks = all combinations of tracks of $P$ with
          a minimum of 3 blips;
        merge concatenated track with best track score in $P$;
    until no tracks can be merged (trackscores>maxTrackscore);
    // Remove non-recent tracks from P
    foreach $p \in P$ with timepoint of latest blip $< (t-2)$ do
        remove $p$ from $P$ if $< 3$ blips;
        move $p$ from $P$ to $B$ if $\geq 3$ blips;
    end
end
```

Algorithm 1: Bird Tracking Algorithm



Zeitintervalle 2.5 Sekunden
Radius 0.75 km
Mittelpunk x:528.0 | y:403.0
Randpunkt x:822.0 | y:410.0

Figure 4: *Image cropping. The red rectangle, defined by the center of the radar monitoring area (P1) and the edge of the circle (P2) specifies the area relevant for the tracking algorithm. Parameters (right) set the image into a spatio-temporal context.*

Images can be browsed to verify the selection. A vertical bar at the bottom (Figure 1) indicates if stacks are cropped (green), omitted by the user (red), or automatically omitted (white) for their small size (tracking on stacks with only a handful of images is not representative). Next, each stack is then computed separately by the detection algorithm (R2). Thereby, omitted stacks are excluded and need to be treated as missing data in further analyses.

5.2. Track Visualization

After executing the detection algorithm (R2), the tracks can be manually examined for quality evaluation (R3). For this purpose, we used a visual encoding that we developed in informal discussions with our domain experts. Here, the course of all bird tracks on the current image are visualized (Figure 1). This enables the user to grasp the total course of all birds visible at each point in time. The path of a bird is modeled as transparent lines, connecting previous, current and later positions of the bird (Figure 5). The transparency allows the user to check the underlying data. To put the visual focus on more recent parts of the tracks, transparency fades out with increasing temporal distance. A bird's positions are rendered as dots, with a larger dot overlaying its current position. All tracks are assigned random colors to distinguish them. We added white lines in an interval of 100 meters so that the flight height can be easily identified. The flight direction can be inferred from its *echo trails*.

All track are listed in a table with additional quantitative information including birdcount (relevant for swarms), time of appearance, height-segment, flight direction, and whether it is a swarm or not (R4). Tracks can be selected in the table, which automatically selects the image of the bird's first appearance, and highlights the track in green (Figure 1). This is especially relevant for swarms—the visual correspondence to the track allows the manually adaption of the bird count (see Supplementary Video 1). For further use, the data can be exported as CSV files.

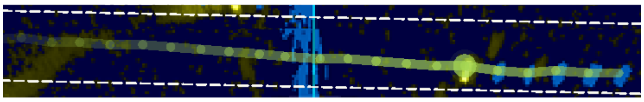


Figure 5: *Visual design of a bird track (green). A large circle shows the current position, smaller circles the previous/next positions of the bird (transparency increases with time difference). The white dashed line indicates the height segment the bird is flying.*

6. Quantitative Evaluation

Testing on annotated distinguished sets for parameter optimization: For the development of the algorithm as well as optimizing its parameters, we applied it to 10 test sets with 25 images each. The test sets vary in background (wind power plants), noise level, flight heights of the birds, and resolution of time (one image per 2.5 seconds or 5 seconds). The ground truth has been manually annotated by a domain expert. We refined the labels manually to count only birds that fulfill the bird track requirements discussed in Section 4. We optimized the parameters to maximize precision/recall. The algorithm identified 110 birds out of 115 fulfilling the requirements with a precision/recall of 0.98/0.94. If we consider all manual annotations instead, the precision/recall drops to 0.92/0.70. This can be explained mainly by birds that did not occur in 3 images. The computation takes about 250-350 milliseconds per image on a consumer level PC, independent of the amount.

Application in an environmental assessment study: Our domain experts used the tool in a real-world application, an environmental assessment study in the "March-Thaya-Korridor" in Lower Austria [rad16]. In this study, the tool was used to assess bird migration in autumn 2014-2016, leading to over 200.000 vertically-recorded radar images. Measurement periods covering about 25.000 images in alternating vertical and horizontal mode lead to 33 valid (vertical stacks) and 42 omitted (horizontal stacks and faulty images) on average. This required 33 cropping actions, since it had to be performed only for the first image of each stack, which took the domain experts only a few minutes. Computation time for such a measurement period was 1:25h. This was considers as acceptable for our domain experts, since it did not require intermediate user interaction.

To test the validity of the tools output, they annotated a sample of 1000 images at 4 locations manually and compared the result to the tool's output. It was found that altogether, 85% of the birds could be detected, which is an even higher rate than the recall of 0.70. It is necessary to mention, that they only compared the amount of detected tracks, not if an individual track is correct or not. At altitudes above 100 meters, the detection rate even increased to 97%-109% of the annotations. We inspected the results manually, which revealed that at lower altitudes (below 300m), radar artifacts lead to a lower detection rate because they obfuscate the radar image. At higher altitudes, the lower frequency of artifacts has the opposite effect: they do not obfuscate, but rather split tracks, which leads to a higher amount of detected tracks.

7. Discussion and Conclusion

Section 6 showed the potential and relevance of our tool in ornithological research, but there is still room for improvements.

The proposed algorithm for bird tracking represents a basic, first approach. Its implementation was not optimized for speed, since it is was not required by the domain experts to get immediate results (i.e. they just run it on the side). Therefore, 250-350 milliseconds per image can be seen as an upper limit for computation time. Although the accuracy was already good enough to be used in an actual ornithological monitoring, there are still measures that could improve the outcome. State-of-the art machine learning methods have the potential to close the gap between the detection rates of birds that fulfill the formulated requirements in Section 4, and the domain expert's annotations. This includes birds with less than 3 *blips*, stitching of flight paths between stacks (i.e. if stacks have been split due to faulty images), automated bird count within swarms, and dealing with occlusions in lower altitudes.

The bird track visualization was used to verify the results to gain confidence in the algorithm output. After testing the tool with domain experts, we consider several enhancements that could improve this process. The track visualization and the table are linked via selection. Adding the track colors to the table would reduce the amount of interactions. Making the tracks more transparent (or hide them entirely) on mouse over would simplify visual inspection.

Structuring the verification process could further increase the confidence in the tool. So far, it is just an informal checking of results of a small sample of a vast collection of images. An automatic, representative sampling of bird tracks, followed by a user-based assessment within the tool would improve the quality of the evaluation. Furthermore, it could even provide quantitative measurements such as precision and recall.

In conclusion, we present an effective tool for automatic bird tracking from time-dependent marine radar imagery that proved its value in an ornithological radar monitoring study. For future projects, we aim to improve the tool with the discussed measures regarding user interaction optimization and adapt it for horizontal radar monitoring (Figure 2a).

8. Acknowledgments

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