A Thesis

entitled

Monitoring of Bird Movement via Marine Radar in the Western Basin of Lake Erie

by

Vamshi Krishna Gummalla

Submitted to the Graduate Faculty as partial fulfillment of requirements for the

Master of Science Degree in Electrical Engineering

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The University of Toledo
December, 2013
An Abstract of
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Development of wind turbines has increased with growing energy needs. Birds mortality rate is the most significant potential impact occurred due to the construction of wind turbines. Since then, radars have been deployed to study the behavior of birds towards wind turbines. Target tracking using radars has been used in order to detect targets (birds). Deployment of commercially available radars was not an option due to budget limitations. Therefore, this project was developed using marine radar and an open source software called radR and generate results comparable to commercially available radar systems. Generally two kinds of studies are conducted, pre deployment and post deployment of wind turbines. In this thesis pre deployment study over Lake Erie has been done. The primary goal of this study was to collect information on the migration characteristics of nocturnally migrating birds, during the Fall and Spring migration period. Specifically, the objective of this study was to collect baseline information on migration characteristics (i.e., flight direction, migration passage rates, and flight altitudes) of nocturnally migrating birds.

This thesis also focuses on developing IMM algorithm for radR. The algorithm is tested on simulated data and real time data in radR to compare effects of the developed
tracker models with the conventional methods in radR. The current tracker models in radR have maximum detection rates with equal false alarm rates. The new tracker model was implemented to reduce these error rates in the data processing.
To my Parents, Grandparents, Family Members and friends, who have been ever supportive of me, guiding and encouraging me through my endeavors.
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A very special thanks to my graduate advisor Dr. Mohsin Jamali for his help and guidance without which this would not be possible. I would also like to thank Dr. Mansoor Alam Chairman of the Department of Electrical Engineering and Computer Science and Dr. Richard Molyet for serving on my committee. My special thanks to Dr. Verner Bingman of the Department of Psychology at the Bowling Green State University (BGSU), Prof. Joseph Frizado of the Department of Geology at the BGSU, Prof. Peter Gorsevski of the Department of Geospatial Sciences at the BGSU and Dr. Jeremy D. Ross of the BGSU for their timely feedback and valuable suggestions. I would like to thank the Department of Energy (Contract #DE-FG36-06G086096) for their financial support. My thanks to Ottawa National Wildlife Refuge (ONWR) for allowing Dr. Jeremy D. Ross the use of their facilities for collection of data during the spring and fall migration period of 2011 and 2012.

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# Table of Contents

Abstract ............................................................................................................................. iii  
Acknowledgements .......................................................................................................... vi  
Table of Contents .............................................................................................................. vii  
List of Tables ...................................................................................................................... x  
List of Figures ................................................................................................................... xi  
1. Introduction .................................................................................................................. 1  
2. Literature review of Radar Studies ........................................................................... 8  
   2.1. Acquiring the radar signal .................................................................................... 10  
   2.2. Commercially Available Marine Radar Systems: ............................................. 11  
   2.3. Summary ............................................................................................................. 18  
3. Marine Radar Based Monitoring System ................................................................. 19  
   3.1. Marine Radar: .................................................................................................... 20  
   3.2. Digitizing Card: ............................................................................................... 24  
   3.3. Radar Signal Processing Software (radR) .......................................................... 30  
   3.4. Radar Signal Processing ..................................................................................... 32  
   3.5. Detection of Targets. ......................................................................................... 33  
      3.5.1. The Learning Phase .................................................................................... 34  
      3.5.2. Sample Scores ........................................................................................... 36
List of Tables

3.1: Models of Furuno Mark 3 ................................................................. 22
3.2: Types of Radiator ............................................................................. 23
3.3: Specifications of the radar ............................................................... 23
4.1: Functions inside the tracker model in radR ................................. 49
4.2: Parameters in the Nearest Neighbor model ................................. 53
4.3: Parameters in MFC model ............................................................. 56
4.4: Parameters in tracks.csv file ....................................................... 56
4.5: Sample Tracks.csv file ................................................................. 57
5.1: Radar Data Collection Dates for Fall and Spring 2011 and 2012 ... 69
5.2: Parameters in tracks.csv file ....................................................... 77
5.3: Antenna settings that need to be changed .................................. 78
5.4: Blip Processing Settings ............................................................... 83
5.5: List of collected parameters ......................................................... 87
5.6: List of data collected and their season to season comparison....... 87
A.1: Final list of Blip parameter settings ........................................... 148
A.2: List of variables from tracks.csv ................................................ 149
List of Figures

2-1: Merlin Avian Radar Unit with dual marine radars [40] ........................................... 11
2-2: Total coverage area of Horizontal Scanning Radar (HSR) and Vertical Scanning Radar [40] ......................................................................................................................... 12
2-3: AR-1 array antenna system located at Seattle airport [41]........................................ 14
2-4: AR-dish system at Seattle airport [41] ..................................................................... 15
2-5: Experimental dual-beam (2-dish) antenna used [42]. ............................................... 16
2-6: Sample of a graph by Detect-Inc systems. ............................................................... 17
2-7: Sample of a graph by Accipiter systems. Daily, unfiltered, track count as recorded by the SEAAR2l radar over a full year, 01 December 2008 to 30 November 2009 [41].... 18
3-1: Experimental setup with XIR3000B digitizing card .............................................. 19
3-2: The experimental setup with the slotted array antenna near a wind turbine in Bowling Green, Ohio ....................................................................................................................... 21
3-3: Marine radar with parabolic antenna near two-blade wind turbine at the University of Toledo ............................................................................................................................... 22
3-4: Block Diagram of XIR3000C ................................................................................... 25
3-5: Heading and bearing signals in radar data ................................................................ 26
3-6: Digitizing card setup................................................................................................. 27
3-7: Radar data in radar sample application .................................................................... 28
3-8: Snapshot of parameters in radar sample application .......................................................... 29
3-9: Scan converted data in radR to represent radar signal elements. ........................................... 31
3-10: Blip Filtering window in radR (Default values) ................................................................. 34
3-11: Structure of a cell (radR) ................................................................................................ 35
3-12: Selected Sample in a cell ................................................................................................. 36
3-13: Sample Classification ....................................................................................................... 37
3-14: Formation of blips ............................................................................................................ 38
3-15: Flow chart of radR process ............................................................................................. 39
3-16: Screenshot of antenna controls ........................................................................................ 42
3-17: Radar Sample without Zone plugin enabled ...................................................................... 43
3-18: Radar Sample with Zone plugin enabled .......................................................................... 43
3-19: Underlay image of radar site on plot window ................................................................. 44
4-1: Types of bird tracks ............................................................................................................ 45
4-2: Target Tracking ................................................................................................................ 46
4-3: Tracker models in radR ..................................................................................................... 46
4-4: Tracking in radR ................................................................................................................ 48
4-5: Algorithm for tracker model ............................................................................................ 49
4-6: NN Model with track 1 created using the minimum distance ............................................. 51
4-7: Sample data in radR ........................................................................................................... 52
4-8: Snapshot of tracks created by the Nearest Neighbor Plugin in radR ................................. 52
4-10: Sample Data in radR ....................................................................................................... 55
4-11: Snapshot of tracks created by Multiframe Correspondence Plugin in radR ............... 55
5-1: The highlighted position represents Ottawa National Park ............................................. 61
5-2: Google Maps view of the Radar site in Ottawa National Wildlife Refuge .............. 62
5-3: Google maps view of radar site ................................................................. 63
5-4: Google maps view of radar site ................................................................. 64
5-5: Radar Trolley with Slotted antenna .......................................................... 66
5-6: Radar Trolley with Parabolic antenna ....................................................... 67
5-7: Airspace sample by the marine Radar when operating in vertical mode (antenna in the vertical orientation) ................................................................. 71
5-8: Airspace sample by the marine Radar when operating in parabolic mode (parabolic antenna is used) ................................................................. 72
5-9: Sample of radar data in radR ................................................................. 76
5-10: Sampled radar data using blip filtering in radR ......................................... 76
5-11: Antenna controls .................................................................................... 79
5-12: Example of vertical T-bar antenna ................................................................ 79
5-13: Example of Parabolic antenna ................................................................... 80
5-14: (a) Parabolic antenna with 0° elevation, (b) 15° elevation ........................... 80
5-15: Parabolic scan before rotating it towards true north ................................. 81
5-16: Parabolic scan after rotating it towards true north ..................................... 81
5-17: Zone plugin for parabolic antenna .......................................................... 82
5-18: Zone plugin for vertical T-bar antenna ..................................................... 82
5-19: Direction of birds flying during Spring Migration 2011 ............................ 88
5-20: Direction of birds flying during Spring migration 2012 ........................... 89
5-21: Direction of birds flying during Fall Migration 2011 .............................. 90
5-22: Direction of birds flying during Fall Migration 2012 .............................. 91
5-23: Flight directions in Spring 2011 on land with respect to different ranges. .......... 92
5-24 : Flight directions in Spring 2011 on water with respect to different ranges. ........ 93
5-25: Flight directions in Spring 2012 on land with respect to different ranges. .......... 95
5-26: Flight directions in Spring 2012 on water with respect to different ranges. ........ 96
5-27: Flight directions in Fall 2011 on land with respect to different ranges.............. 97
5-28: Flight directions in Fall 2011 on water with respect to different ranges............ 98
5-29: Flight directions in Fall 2012 on land with respect to different ranges............. 99
5-30: Flight directions in Fall 2012 on water with respect to different ranges.......... 100
5-31: Total number of birds detected per hour with vertical T-bar antenna during Spring
2011................................................................................................................................. 101
5-32: Total number of birds detected per hour with parabolic antenna during Spring 2011
........................................................................................................................................... 102
5-33: Total number of birds detected per hour with vertical T-bar antenna during Spring
2012........................................................................................................................................ 103
5-34: Total number of birds detected per hour with parabolic antenna during Spring 2012
............................................................................................................................................... 104
5-35: Total number of birds detected per hour with T-Bar antenna during Fall 2011.... 105
5-36: Total number of birds detected per hour with parabolic antenna during Fall 2011
............................................................................................................................................... 106
5-37 : Birds detected per hour with parabolic for Fall 2012....................................... 107
5-38 : Birds mean flight velocity for T-Bar during Spring 2011............................... 108
5-39 : Birds mean flight velocity for parabolic during Spring 2011......................... 108
5-40 : Birds mean flight velocity for T-Bar during Spring 2011............................... 109
Chapter 1

Introduction

1. Introduction

Wind energy is the fastest growing sectors of energy industry [1]. Recent studies [2-3] have shown that wind farms may have some environmental concerns. Number of bird fatalities has been recorded, including death from colliding with turbine blades [4]. This has led to the emergence of different kinds of Environmental Impact Assessments (EIA) analysis for the study of impacts of onshore/offshore wind farms on nocturnal migrating birds.

An understanding of the movement of nocturnal bird migration at a particular location will help us in estimating probabilities for bird collisions with the wind turbines. Analysis of nocturnal migration is important because considerably more birds migrate at night than during the daytime [5]. Nocturnally migrating birds are at higher risk of colliding with the wind turbines. Given the occurance and the interest in bird migration in general, it is surprising that baseline data on nocturnal bird migration are lacking for most regions of the United States.

Many different methods have been used to study nocturnal bird migration. Direct visual studies have been conducted using telescope or binoculars by viewing birds crossing the face of the moon (moon watching technique) [6] or watching birds passing through a
narrow, vertical light beam (ceilometers technique) [7], and acoustic monitoring of flight calls [8, 56]. Results from these methods depend on many external factors; therefore they are not reliable and do not provide accurate information on the distance or altitude of migrating birds.

Radio Detection and Ranging (Radar) has been used for the detection of nocturnal flight activity of birds, insects, and bats [9-23]. Radar operates by transmitting radar signal and then receiving echoes that are reflected back from an object (e.g., birds, ships, trees, etc). Since radio waves travel close to the speed of light, the distance of the object from the radar can be determined by calculating the time taken for transmitting and receiving the echo signal [24-25]. Reflected power from a given target is computed using famous radar equation available in most radar books. The radar equation is the ratio of radar echo produced by a target and is follows [24-25]:

\[
P_r = \frac{P_t \cdot G^2 \cdot \lambda^2 \cdot \sigma}{(4\pi)^3 \cdot R^4}
\]  

(1.1)

Where

\[ P_r \text{(Watts)} = \text{Received power from the echo} \]

\[ P_t \text{(Watts)} = \text{Radar transmitted power} \]

\[ G = \text{Antenna gain, or amplification} \]
\( \lambda \text{ (m)} = \text{Wavelength of the radar} \)

\( \sigma \text{ (m}^2) = \text{Radar cross section (RCS)} \)

\( R \text{ (m)} = \text{Maximum range to the target} \)

Estimation of minimum area of a target is commonly called Radar Cross Section (RCS) at a particular range. The maximum range at which the target can be detected depends on antenna gain, power of the radar, wavelength of the radar. In order to double the range of the radar then its transmitted power would have to be increased by 16-fold. It is due to the power of four factor in the radar equation it will also require quadrupling the antenna gain. Since birds have a small RCS so their returns are very small.

Antenna gain is directly proportional to the area of antenna [24]. Therefore, a larger antenna will help in detecting targets at farther ranges [14]. The radiation patterns produced by antennas are called lobes and they can be characterized as ‘main lobe’ and ‘side lobes’ [25]. Beam width is defined as the angular range of the antenna pattern in which at least half of the maximum power points of the main lobe. Detection of targets beyond the half of the maximum power points is also possible depending on range and echo strength reflected from the target.

The most popular radar used for bird migration research studies is the marine radar. A slotted waveguide array antenna is normally used in horizontal or in vertical orientation. Array antenna sends out a fan-shaped beam 360° around its location with horizontal
beamwidth of ~1-2° and vertical beamwidth of ~20°. In horizontal orientation the radar returns the x and y coordinates for the targets detected within its range. Because of the wide vertical beamwidth (~20°) height, information (z) cannot be extracted. In vertical orientation the radar returns target altitude across the scan providing y (distance) and z (height) information. In contrast, a parabolic dish antenna produces a pencil beam. Beam width of a parabolic dish depends on the focal length, wavelength of the radar (2.5-3.75 cm for X-band) and the diameter of the dish. When the angle of elevation of parabolic dish is greater than zero, by using simple arithmetic’s users can calculate the spatial information of the target (x, y (range) and z (height)). Array antennas are readily available since it’s the standard equipment used on boats. Parabolic dish antennas have to be custom made for the radar or use already available military surplus equipment.

Probability of detection of small birds increases with the decrease in wavelengths [23]. In order to maintain constant beamwidth, the size of antenna is directly proportional to wavelength. Noise due to rain can be avoided using long waves at the expense of ability to detect smaller targets [25]. Therefore, smaller wavelengths radars such as X-band (2.5 to 3.75 cm) are optimal for detection of smaller targets [23].

In spite of using radar for biological studies for a long period of time, its general usage has many challenges. Manual methods such as videotaping the radar screen and manually recording the bird data by marking on radar display have been used in the past. They are cumbersome, unreliable and time consuming. There are few manufacturers who provide radar based data collection systems and processing software. These radar systems
and their software cost upwards of $250,000 and are out of the range for university research. One of the goals of this work is to digitally collect radar data and process it with cost effective processing tools.

Furuno 1500 Mark 3 marine radar is used in this project for bird detection. It is X band marine radars and have been very popular for bird studies. A 25 K Watt marine radar unit used in this project provides reasonably high resolution. The main advantage of using a marine radar over Doppler and tracking radar is that they are relatively inexpensive, commercially available, easy to maintain, easy to operate, have high resolution, and can be used to collect altitudinal information.

An open source software program “radR” [15] from Acadia University in Canada is widely available for research purposes. This work uses radR software in conjunction with a digitizing card. The open source radR can extract the digitized signal, derive target information and can archive the data. It features target detection and track formation. It is capable of recording fully processed data so that repetitive processing can be avoided. A graphical interface allows changes in processing parameters and customization via user-defined functions written in the R language. Users will have access to each stage of data processing. New promising techniques can also be added to radR software. Realistic tracking algorithms are applied on raw data in order to extract putative biological targets. At present, two target tracking algorithms are implemented in radR: Nearest Neighbor (NN) algorithm and Multi Frame Correspondence (MFC) algorithm. For data association, model uses an algorithm from the Stanford Graph Base Package of Knuth [16].
A single radar tracking model may not provide accurate description of behavior of migrating birds and bats. Advanced track building models will be useful for increasing the probability of detection and tracking of a bird. Estimation techniques used for bird tracking should use different models to predict the target motion. Therefore, an appropriate target tracking technique may be required to increase the accuracy and reliability of detected target outputs.

In this research a single radar unit was deployed in an area that has potential for future wind farm development. The area has been identified as having high winds that are also attractive for off-shore wind turbine development. The study area is Ottawa National Wildlife Refuge (ONWR) half way between Oregon and Port Clinton, Ohio. The ONWR is a part of the major stopover of migrating birds due to abundance of food, water and shelter. The study was designed to observe the airspace for approximately 45-60 days during high migration periods of the spring (late April through early May) and fall (late August through early October). The monitoring system consist of a marine radar, IR camera and acoustic recorders for bird and bat calls. This thesis devotes on radar monitoring of migratory birds and produces data that will be useful to wild life biologists for siting of wind turbines. Monitoring was done between civil sunset and civil sunrise hours, assuming this to be peak period of nocturnal migration for birds on a given night.

This thesis is organized as follows

- Chapter 1: This chapter is the introduction to the thesis. It discusses the motivation behind the work. An overview of the thesis is provided to clarify the aim of this work
• Chapter 2: This chapter provides a survey of radar studies. It provides the basic steps to be taken in order to implement a radar study. Analysis is provided on different radar models used in radar studies.

• Chapter 3: This chapter introduces radR software program.

• Chapter 4: This chapter discusses various tracker models present in radR software program.

• Chapter 5: This chapter discusses results obtained during the Spring and Fall of 2011 and 2012 migration season. This chapter also discusses various steps involved in processing and post processing of radar data.

• Chapter 6: Conclusions and future work on this topic are given.
Chapter 2

Literature review of Radar Studies

2. Literature review of Radar Studies

Recent technological advances have meant that smaller ‘marine’ radars (scanning radars) are now more portable and relatively inexpensive, making them better suited for studying bird movements. Pioneers in the field of radar ornithology have extensively used ‘mobile radar units’ [5]. Some have modified antennas so that altitude information can be collected [10] and unwanted noise (clutter) in the signal can be reduced [11]. Others have developed techniques for automated sampling of radar data, and have merged radar technology with other observational method [21] to differentiate birds from insects. Many of the practical applications of radar as applied to studies of bird migration are outlined by [13] [14]. Gauthreaux [13] and Larkin [14] provided a comprehensive overview for understanding radar data and addressed radar setup issues such as clutter reduction etc. The increase in usage of these methods has led to their usage near onshore/offshore wind farms [19-22]. However, little was mentioned regarding the collection of radar data and no solutions was provided for automating the process.

Gauthreaux et al. [13] has equipped radar with a Geographical Positioning System (GPS) to locate the latitude and longitude of the target. The marine radar results are
correlated with the WSR 88D data [13]. Taylor et al [15] have addressed main technical considerations that should be used for radar study.

1. Type of radar and antenna
2. Configuring and setting up of the radar
3. Acquiring the radar data

McFarlane et al. [34] calculated bird densities based on the probability of the target being a bird based on distance between observer and target. Bird densities were computed as birds per kilometer square. Kerlinger et. al. [35] noticed that wind increase can cause ground speed of birds and may contribute to drifting of migration path. Gauthreaux et al. [36] have also developed another method of validation by comparing vertically pointing fixed beam radar with the thermal camera data.

Radar setups are not readily available for biological surveys. Therefore, tuning of the radar is a must for obtaining optimal results. Some of the radar features which have to be taken care of when is used for biological survey are radar tuning, auto gain, interference rejection, removal of rain and sea clutter settings.

In most of modern Marine radar systems, radar controls offers the ability to transform the return signals. Parameters such as gain, ‘rain clutter’ and ‘interference rejection’ can be applied by the user to the returned radar signal. These settings are used to improve the ability to detect targets on radar display. Gain controls adjust receiver sensitivity. When the targets are detected at a longer range this control can be adjusted to detect targets with
low background noise. At higher gain the entire received signal is displayed including noise, when using lower gain only larger targets are displayed. Therefore, it is vital to choose the appropriate gain for a give range resolution. ‘Rain clutter’ control will suppress the echoes returned from rain, snow, etc.

In order to detect birds using marine radar gain should be high, thus setting maximum sensitivity to the receiver in order to detect birds. Sea and rain clutter should be turned off; birds which travel in dense flocks will be detected as noise instead of a target. The final aim here should be to generate maximum amount of information which can be related linearly to the output of the radar digitizing card.

Interference Rejection will help us reduce the interference effects created by nearby radar operating on the same frequency band. When interference rejection is turned one small signal returns are filtered out, therefore this might also filter out small targets detected by the radar and should not be used.

2.1. Acquiring the radar signal

In the past several different methods have been used to collect radar data, including film [37], overlaying of transparent sheets on Plan Position Indicator (PPI) [10] and video frame grabber. Using these methods it’s not possible to receive accurate information while processing. In order to get maximum amount of information from received signal special analog to digital converters are used. These are called “Radar Digitizing cards”.
2.2. Commercially Available Marine Radar Systems:

Mobile Avian Radar System (MARS) by Geo-Marine uses X-band marine radar with T-bar antenna operating in vertical and horizontal modes. The horizontal mode can provide range, direction and speed of the target. While vertical mode can provide altitude [38].

Figure 2-1: Merlin Avian Radar Unit with dual marine radars [40]

DeTect Inc [39] [40] manufactures and supports the MERLIN radar systems. MERLIN system uses dual marine radars. One of them is a 25- kW power operating in X-band frequency (3 cm wavelength). It serves as Vertical-Scanning Radar (VSR) sensor. The second one is a 30-kW power operating in S-band (10 cm wavelength. It is a
Horizontally-Scanning Radar (HSR) sensor as shown in Figure 2-1. The VSR operates in the vertical (y-z) plane as shown in Figure 2-2. VSR helps in detection and tracking of targets that pass through or along the vertical beam, velocity, recording target area and height attributes. The HSR or S-band radar operates in the horizontal (x-y) plane as shown in Figure 2-2. The S-band is used for greater detection range and less signal interference from surrounding vegetation (ground clutter) and weather. HSR data is mainly used in determining direction of birds.

DeTect Inc [39] [40] is developing software to determine wing beat frequency for identification of bird species. If the bird is tracked by the radar beam then the fluctuations in the target echo can be used to obtain the wing beat frequency. The wing beat frequencies help in identifying the species and differentiating birds from bats. Fixed vertical beam radar with beamwidth large enough to allow large as well as slow moving birds within the beam for a few seconds is used to measure its wing beat frequency.
Accipiter radar systems first developed analog radars with manual tracking called as BirdRad. This system was built by Dr. Gauthreaux using a Furuno 2155BB radar sensor and parabolic dish antenna. The upgrade to BirdRad is eBirdRad which uses digital radars with automatic tracking. eBirdRad system includes a radar interface board which digitizes the raw video signal. In 2006 accipiter developed AR-1 and AR-2 systems. AR-1 radar has a single radar sensor equipped with a 6 ft slotted array antenna as shown in Figure 2-3. AR-2 is equipped with 4° parabolic dish antennas as shown in Figure 2-4. AR-2 has two dishes set at different up-tilt angles. The AR2-L (low) is a 4° beam tilted to center at 2° above horizon. Hence this sensor covers from horizon to 4°. The AR2-H (high) is a 4° beam tilted
to center at 6° above horizon. Hence the AR2-H covers from 4° to 8° [41]. A dual beam antenna was custom built on two standard dish antennas to a

Figure 2-3: AR-1 array antenna system located at Seattle airport [41]
Figure 2-4: AR-2 dual dish system at Seattle airport [41]

modified Furuno FR8252 transceiver [42] as shown in Figure 2-5. The radar connection is switched between two dishes alternately from one pulse to the next and the data stream tagged to indicate which antenna was active for each pulse.
Figure 2-5: Experimental dual-beam (2-dish) antenna used [42].

A sample graph generated by Detect Inc. systems is shown in Figure 2-6. A sample graph generated by Accipiter system is shown in
Target passage rates at the proposed Wind Project site during days and nights of spring migration 2009 are shown in Figure 2.7 [39].
Figure 2-7: Sample of a graph by Accipiter systems. Daily, unfiltered, track count as recorded by the SEAAR2I radar over a full year, 01 December 2008 to 30 November 2009 [41].

2.3. Summary

Radars used in avian study and the extensive usage of marine radars in the field of ornithology was explored. Various techniques implemented to reduce clutter and the data processing methods for bird identification in the marine radar data was also discussed. The 3-D information of targets is obtained using a parabolic antenna. A t-bar antenna can be used in the vertical mode to extract the altitude information of birds. Different commercially available systems are described. In the following chapter the experimental setup to collect data using marine radar and the data processing software radR is discussed.
Chapter 3

Marine Radar Based Monitoring System

3. Marine Radar Based Monitoring System

Marine radar has been used for bird observation and quantification of their activity for number of years. The radar data is collected using a digitizing card XIR3000B from Russell Technologies. radR is used for processing of collected data for target detection and tracking. The experimental setup of the entire system is shown in Figure 3-1.

Figure 3-1: Experimental setup with XIR3000B digitizing card
The marine radar is connected to the digitizing card and as the antenna rotates the signal is transmitted to the digitizer. The received signal is digitized and transmitted to a laptop/PC through the USB. The radR is used for post processing of the saved files.

3.1. Marine Radar:

Furuno 1500 Mark 3 marine radar is used in this project for bird detection. X-band marine radars with higher resolution are preferred for bird detection. The marine radar and its antennas are shown in Figures 3-2 and 3-3.
Figure 3-2: The experimental setup with the slotted array antenna near a wind turbine in Bowling Green, Ohio
Figure 3-3: Marine radar with parabolic antenna near two-blade wind turbine at the University of Toledo

There are different models of Furuno marine radars as shown in Table 3-1.

Table 3-1: Models of Furuno Mark 3

<table>
<thead>
<tr>
<th>Radar Model</th>
<th>Power (KW)</th>
<th>Radiator Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>FR- 1505 Mark 3</td>
<td>6</td>
<td>XN12AF, XN20AF</td>
</tr>
<tr>
<td>FR- 1510 Mark 3</td>
<td>12</td>
<td>XN12AF, XN20AF</td>
</tr>
<tr>
<td>FR- 1525 Mark 3</td>
<td>25</td>
<td>XN20AF</td>
</tr>
</tbody>
</table>

Specifications for different types of slotted waveguide are given in Tables 3-1 and 3-2.
Table 3-2: Types of Radiator

<table>
<thead>
<tr>
<th>Radiator Type</th>
<th>XN12AF</th>
<th>XN20AF</th>
<th>XN24AF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (Ft.)</td>
<td>4</td>
<td>6.5</td>
<td>8</td>
</tr>
<tr>
<td>Beamwidth (H)</td>
<td>1.8°</td>
<td>1.23°</td>
<td>0.95°</td>
</tr>
<tr>
<td>Beamwidth (V)</td>
<td>20°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sidelobe ±10°</td>
<td></td>
<td>-28 dB</td>
<td></td>
</tr>
<tr>
<td>Polarization</td>
<td></td>
<td></td>
<td>Horizontal</td>
</tr>
</tbody>
</table>

Specifications of the radar used in this project are given Table 3-3. The radar map provides the geographical information of the area. It has an Automatic Tracking Aid (ATA). Its Electronic Plotting Aid (EPA) allows plotting tracks up to ten targets.

Two types of antennas are used in this project and they are slotted array and the parabolic antenna. The marine radar usually has slotted array antennas of three types as discussed in Table 3-2.

Table 3-3: Specifications of the radar

<table>
<thead>
<tr>
<th>Specifications of Marine Radar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>9410 MHz ± 30 MHz (X-band)</td>
</tr>
<tr>
<td>IF</td>
</tr>
<tr>
<td>60 MHz</td>
</tr>
<tr>
<td>Power</td>
</tr>
<tr>
<td>25KW</td>
</tr>
<tr>
<td>Noise Figure</td>
</tr>
<tr>
<td>6 dB</td>
</tr>
<tr>
<td>Range Accuracy</td>
</tr>
<tr>
<td>1% Maximum Range</td>
</tr>
<tr>
<td>Bearing Accuracy</td>
</tr>
<tr>
<td>± 1°</td>
</tr>
<tr>
<td>EPA</td>
</tr>
<tr>
<td>10 targets</td>
</tr>
<tr>
<td>ATA</td>
</tr>
<tr>
<td>20 targets</td>
</tr>
</tbody>
</table>
The acquired marine radar is used to collect data during the migratory seasons. The data collection is divided into three time slots which are evening civil twilight, morning civil twilight and night time observations. The slotted array antenna is used during the morning and evening civil twilights with the antenna rotation around the horizontal axis (vertical mode). It is the time when the birds ascend (evenings) and descend (mornings). The horizontal beam width is 1.23° and provides greater target discrimination, detectability and resolution. This mode helps in detecting the height of targets and hence the ascend and descend of targets can be detected accurately. The night time observations are done using the parabolic antenna which covers wider area and targets are detected along with heights and the angle of arrival.

3.2. Digitizing Card:

A typical radar display will only offer seven levels of intensity values received from the echo, whereas the current radar digitizing cards can offer up to 4096 levels of intensity (12 bits) from the same signal. Therefore, extracting raw signal from radar will help us to obtain more information about targets compared to a standard radar display. The digitizing card is used in the slave mode and files are saved in the form of .REC files. They consist of image frames. The block diagram of XIR3000C is shown in Figure 3-4.
In the slave mode the digitizing card requires four input signals from the transceiver which are azimuth, heading marker, trigger and video signals. The XIR3000 has:

- USB bus
- 100MHz sample rate
- Compatible with all PCs and transceivers
- Software Development Kit (SDK) for customization
- Automatic Radar Plotting Aid (ARPA) tracking
- Ethernet with TCP/IP

The Russell Technologies Inc. Software Development Kit (RTI SDK) provides options for scaling, image and display. The SDK has following features:

- Header, RTI DLL and library files
- Radar sample application which allows viewing and saving of radar images
• MS VC++ sample files
• Clutter and interference suppression
• Antenna Control Module (ACM)

Figure 3-5: Heading and bearing signals in radar data

If these signals are not received correctly then ‘missing’ appears next to the signal in the radar sample software [44]. Radar is a master and the digitizing card is in the slave as shown in Figure 3-6. The input of the digitizing card is from the transceiver and the output is an USB connection to the laptop or PC with radar sample application.
Figure 3-6: Digitizing card setup
The snapshot of radar sample application is given in Figure 3-7.

Figure 3-7: Radar data in radar sample application
Various parameters of radar digitizing card are shown in Figure 3-8. Its “Status” box should be monitored and has following three main signals:

- Bearing Pulse
- Ship Heading Marker
- Trigger

They may have status of OK, Missing or Error. If any of the signals is missing, then their documentations should be followed to correct the situation.
3.3. Radar Signal Processing Software (radR)

radR is an open source platform for visualizing and recording radar data [15]. It is useful for processing of Marine radar data. It can be used for comparing, evaluating radar hardware, developing and testing new algorithms. radR can be used with wide variety of radar types of antenna, wavelengths, and radar brands. This tool is mainly developed for research purposes, therefore; it is flexible and extensible by design. radR program utilizes data from the Marine radars in surveillance mode (scanning a particular volume of space repeatedly).

R and C languages were used to write the program for radR [45]. R is an open source programming language which has wide variety of statistical tools readily available for post processing of data; it can be used with different operating system such as windows, Linux [45]. But at this moment radR can only be interfaced with certain specific proprietary radar digitizing cards available in the market. radR program has very interactive GUI interface similar to the existing media players and allows following functions:

- Allows user to choose input and output values
- Start and stop processing
- Vary playback speeds
- Displaying of data
- Target finding (target detection)
- Tracking algorithms.

The input to radR is given in the form of a matrix which contains set of integers known as the “scan” representing the received signal power from the pulse at a uniformly
spaced times through radar’s rotation as shown in Figure 3-9. Each row contains range values for that particular angle. Columns represent angle in degrees. Each column in the matrix represents a time-series of power received by the radar antenna in a short time-window after the radar has transmitted a single pulse of microwave energy. Each row in the scan matrix corresponds to the energy received from a given "range cell", with individual numbers representing the energy received while the radar was pointing at a particular azimuth.

Figure 3-9: Scan converted data in radR to represent radar signal elements.

Since, radR is a post processing tool, scan matrix is processed in order to filter clutter or noise. It extracts possible targets from the input data. Different functions written in R are used to process data from the input scan matrix for different stages of processing (called as “hooks”). Various plugins are available for processing and modification of the data, implement different functions such as blip filtering and tracking etc.
3.4. Radar Signal Processing

radR takes digital signal received from radar system as its input. Acquiring the analog signal from radar systems is the most critical part in this research. Radar digitizing card converts the analog radar signal to digital signal for further processing. Currently, radR supports number of digitizing cards. For our research purposes a digitizing card acquired from Russell Technologies Inc., “XIR3000B card” has been used. The output file from this digitizing card is in “.rec” format. A plugin is available to read the .rec format file. The radR is hardware independent software and can be customized with various plugins to achieve certain goals.

The acquired scan radar data is in the form of matrix. This matrix is generally referred to as raw data. The radar antenna sends out electromagnetic pulses and listens for echos. The received echo is converted from analog to digital signal. The digitized signal is converted to a sequence of sample values. The sample values are integers with a range of 0 to \(2^b - 1\) where b is bit value per sample. Digitizing cards are designed to produce samples with b-bits. Number of bits may be 8 or 12 giving a sample range of 0 to 255 or 0 to 4095 [46]. Rows in scan matrix represent the energy received by the radar at a particular distance from the radar for the entire sweep of 0\(^0\) to 360\(^0\). Columns in scan matrix represent the energy received by the radar in an azimuth angle with increase of distance from the radar.

\[
\begin{pmatrix}
    x^{d_1}_{a_1} & \cdots & x^{d_n}_{a_1} \\
    \vdots & \ddots & \vdots \\
    x^{d_1}_{a_m} & \cdots & x^{d_n}_{a_m}
\end{pmatrix}
\]
$x_{an}^d$ Represents energy received by the radar at distance $n$ and angle $m$. The distance $n$ represents number of columns and are from one to 512. The angle $m$ represents number of rows and are from one to 4096. The matrix size will be (4096 x 512).

3.5. Detection of Targets.

Extraction of moving targets from the received radar signal in radR is performed in different phases of learning, computing sample score, classifying sample score, formation of blips and track formation. Assign track identification to blips under certain conditions. Blip finding method in radR uses different parameters which are given as user inputs. Default blip parameters are shown in Figure 3-10
3.5.1. The Learning Phase

radR starts with calculating mean and deviation of the received radar signal from the sample window selected by the user for certain number of user specified scans. This acts as a background.
Figure 3-11: Structure of a cell (radR)

Figure 3-11 shows a structure of a cell. Selected sample value in a cell is shown in Figure 3-12. A cell P consists of \( i \) number of samples and \( j \) number of pulses. User can define or vary values of \( i \) and \( j \). Cell mean and cell deviation are calculated for 15 scans as:

\[
\text{cellmean} = \frac{\sum P[i,j]}{20}
\]  

(3.1)

\[
\text{celldeviation}(t) = \frac{\sum |P[i,j] - \text{cellmean}(t)|}{20}
\]  

(3.2)

where \( t \) varies from one to number of learning scans set. Average of cell mean and deviation is considered as running cell mean and deviation. They are computed as:

\[
\text{runningcellmean}(15) = \frac{\sum \text{cellmean}(t)}{15}
\]  

(3.3)
3.5.2. Sample Scores

Individual sample scores for each particular cell are calculated using the background information from the previous scans. This is nothing but the energy received by the radar signal at a particular range and the corresponding azimuth.

\[
\text{runningcelldeviation}(15) = \frac{\sum \text{celldeviation}(t)}{15} \tag{3.4}
\]

For example from Figure 3-12, the sample score of the highlighted box is

\[
\text{sample} = P[3,2] - \text{runningcellmean}(15) - \text{runningcelldeviation}(3,2) \tag{3.5}
\]
3.5.3. Classification of samples

A sample is hot if its score is either above the hot score threshold. It is cold if its score is below the cold score threshold. For radar data, “cold” blips are not needed, so the cold score threshold should be set to a big negative integer (e.g. -128).

Figure 3-13: Sample Classification

Samples are divided into hot and cold classes as shown in Figure 3-13

Condition for hot and cold classes are as follows:

if sample score \([i, j]\) \(\geq\) hot threshold or \(<\) cold threshold

sample class \([i, j] = \text{hot}\)

if sample score \([i, j]\) < hot threshold or \(\geq\) cold threshold
sample class \([i, j] = \text{cold}\)

3.5.4. Finding and Filtering Blips

Sample values which satisfy the user specified filtering conditions are combined to form blips as shown in Figure 3-14. User specified filtering conditions that needs to be considered are as follows:

- Minimum and maximum number of samples required to form a blip
- Minimum and maximum area of the blip formed
- Minimum and maximum angular span of the blip formed
- Minimum and maximum radial span of the blip formed

![Figure 3-14: Formation of blips](image)

38
A flow chart of radR process is shown in Figure 3-15

3.5.5. Track formation algorithms

Tracks are built by associating blips from different scans. Building tracks depends on following properties:

- The distance of a blip from the last point of an existing track
The turning angle of a track
The speed of a blip
The area and intensity (represented by color) of a blip

Currently, there are two different tracking algorithms implemented in radR. They are Nearest Neighbor (NN) algorithm and Multi Frame Correspondence (MFC) approach. In the nearest neighbor model tracks are formed using a very simple method. This algorithm first calculates the distance between all the detected blips in the present scan and the blips or existing tracks detected in the previous scan. This model tries to join blips to nearby tracks in such a way that, overall, blips and tracks get matched well (so that no blip is too far from the track to which it is assigned) with some constraints. All possible pairs of blips are again filtered using parameters such as speed, area, intensity and turning angle. Resulting blips to tracks are matched in such a way that no blip is matched to more than one track. No track is matched with more than one blip. All the unmatched blips form a new track.

The Multi Frame Correspondence (MFC) model uses non-iterative greedy algorithm for generation of tracks. This model uses two scans; blips are matched between these two scans using the simplistic nearest neighbor model. After detecting possible matching blips, the algorithm assigns a velocity to these sets of matched blips. With the processing of the third scan, all possible pairs from previous two scans and current scan are considered. There may be a chance that some targets may not be detected as blips during the filtering of the noise and the clutter. Those targets cannot be tracked.
3.6. Other radR plugins

Table 3-1 lists available radR plugins and their functional description.

<table>
<thead>
<tr>
<th>Plugins</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>antenna</td>
<td>Antenna selection</td>
</tr>
<tr>
<td>seascan</td>
<td>Obtains data from Rutter Inc. Sigma S6 digitizing card</td>
</tr>
<tr>
<td>seascanarch</td>
<td>Reads data saved by Rutter seascan software</td>
</tr>
<tr>
<td>xir3000</td>
<td>Obtains data from XIR3000 USB video processor</td>
</tr>
<tr>
<td>xir3000arch</td>
<td>Reads data saved by RTI software</td>
</tr>
<tr>
<td>video</td>
<td>Reads video data</td>
</tr>
<tr>
<td>declutter</td>
<td>Removes noise</td>
</tr>
<tr>
<td>tracker</td>
<td>Creates tracks of targets</td>
</tr>
<tr>
<td>zone</td>
<td>Excludes data within the defined region</td>
</tr>
<tr>
<td>genblips</td>
<td>Generates artificial blips</td>
</tr>
<tr>
<td>saveblips</td>
<td>Saves blip information in .blips file</td>
</tr>
<tr>
<td>blipmovie</td>
<td>Saves data in blip movie format</td>
</tr>
<tr>
<td>underlay</td>
<td>allows display of a geo-referenced GIF image under the plot window</td>
</tr>
<tr>
<td>pointerinfo</td>
<td>Pops up a window describing what's under the cursor in the plot window</td>
</tr>
</tbody>
</table>

These plugins are used during different phases of processing. There are two type of antennas used in this project. Antenna plugin allows selection of one of two antennas. Figure 3-16 shows set values of the parabolic antenna. Table 3-2 lists setting of both antennas. Zone plugin helps in removing selected area of the ground clutter. In this project, zone plugin is used to exclude data of 375 meters around the radar when parabolic antenna is used. Figures 3-17 and 3-18 show samples scan of with and without zone plugin respectively. Underlay plugin allows a geo-referenced GIF image to be displayed under the plot window. Figure 3-19 show an underlay image of radar site for this project.
Figure 3-16: Screenshot of antenna controls

Table 3-2: Setting for Antennas

<table>
<thead>
<tr>
<th>Antenna Settings</th>
<th>Parabolic</th>
<th>Slotted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of beam above rotation plane in degrees</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Horizontal aperture of beam (has no effect )</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Vertical aperture of beam (has no effect )</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Bearing offset</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Elevation of radar</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>True range of first sample</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Rotation axis: elevation above horizontal</td>
<td>90</td>
<td>0</td>
</tr>
<tr>
<td>Rotation axis: direction of tilt</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Figure 3-17: Radar Sample without Zone plugin enabled

Figure 3-18: Radar Sample with Zone plugin enabled
3.7. Summary

The marine radar and the digitizing card XIR3000B used in the project is discussed. The radar data is processed in radR software. Various plugins in radR and the importance of blip processing parameters for accurate target identification is given in detail. The following chapter discusses tracking and the current tracker models in radR.
Chapter 4

Target Tracking

4.1 Introduction

The goal of the target tracking is to provide the location of any target of interest. Many external unwanted sources along with the target are present in the radar data. Unwanted sources may be from buildings, vegetation, water waves and weather. Any unwanted source is classified as clutter and need to be removed. Presence of clutter makes target tracking very challenging. Tracking algorithms play an important role in removing unwanted targets. Due to the presence of external sources or undesired targets in radar data, tracking algorithms can help in target detection and clutter removal.

This project focuses on vital analysis of effects of man-made structures on migration patterns of birds. Figure 4-1 shows various types of bird tracks and it can be seen that they have no regular patterns.

Figure 4-1: Types of bird tracks
4.2 Tracker Models in radR

Marine radars work in surveillance mode and need tracking algorithm for generation of tracks. Marine radars locate targets first and then track. There are multiple targets and the system uses the approach of tracking while scanning [48]. Figure 4-2 shows various steps involved in target tracking.

![Figure 4-2: Target Tracking](image)

The open source software radR has algorithms for radar data recording, detecting, tracking and saving target information. At present, radR uses the Nearest Neighbor model (NN) and the Multi Frame Correspondence (MFC) tracker plugin (model). The NN algorithm is based on minimum distance and MFC tracking is based on maximum gain. Figure 4-3 shows two current tracker models in radR [49].

![Figure 4-3: Tracker models in radR](image)
There are number of plugins for processing radar data in the radR. Player and tracking plugins in radR are used to run the radar data and tracks are created as files are processed. The processed data is saved in .csv files with all the blip information such as time stamp, track number, scan number, blip number, x-coordinates, y-coordinates, z-coordinates, intensity, area, perimeter, radial span, angular span and number of samples of each blip. Tracker plugin (model) allows selection of the appropriate tracker model. While tracking, unwanted targets are removed by setting threshold values for velocity and the number of blips required to form a track.

4.3. Tracker Model:

Old data points are read by tracker model from previous frames. All the data from the current scans are stored as blips. Previously stored blips and current blips are matched using tracker model. Gain function is created to store tracks with matched blips. Blips without any match start their own track. Figure 4-4 shows steps involved in radR.
There are various types of functions in the tracker model as shown in Table 4-1. Each function in the tracker model has a unique task. Tracks are updated using update function by starting a new track or adding blips to the existing track. The update function implements tracker algorithm where matched blips are selected and are given in the form of gain function which stores the column index of the matched blips. Get menu function accepts user inputs of the minimum number of blips and maximum speed in order to form a track. The expiry time of the track is set by the set blip fresh time function and if controls are changed while running the data then the tracks are refreshed. Other functions used in this work are select, deselect, load and unload plugin. Figure 4-5 shows the radR tracker model layout.

Figure 4-4: Tracking in radR
Table 4-1: Functions inside the tracker model in radR

<table>
<thead>
<tr>
<th>Functions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Update</strong></td>
<td>Tracking algorithm identifies best matched blip for each track.</td>
</tr>
<tr>
<td><strong>Get menu</strong></td>
<td>It is used to control parameters to create track dynamically.</td>
</tr>
<tr>
<td><strong>Select</strong></td>
<td>Select function defines the onset of a track.</td>
</tr>
<tr>
<td><strong>Deselect</strong></td>
<td>Deselect function defines the expiry time for a track.</td>
</tr>
<tr>
<td><strong>Load</strong></td>
<td>Load is used to enable the tracker model.</td>
</tr>
<tr>
<td><strong>Unload</strong></td>
<td>Unload is used to disable a tracker model.</td>
</tr>
<tr>
<td><strong>Set blip fresh time</strong></td>
<td>Defines the time for which a blip is retained in the frames.</td>
</tr>
<tr>
<td><strong>Set track stale time</strong></td>
<td>Defines the time for which a track is active.</td>
</tr>
</tbody>
</table>

Figure 4-5: Algorithm for tracker model
4.3.1. Nearest Neighbor Model:

The NN model uses minimum distance method to build tracks. The minimum distance between blips of the current frame to the ones on the previous frame is calculated [50]. Velocity, turning angle and the blip size are used in the filtering process of the tracks. Distance is calculated between blips in the current and previous frames. All possible combination of distances are stored in a matrix. Maximum distance is computed for each blip and stored in a row of the distance matrix. Gain is calculated for each blip using the following relation:

\[
\text{Gain} = 100 + \max(\text{distance}) - \text{distance of each blip} \quad (4.1)
\]

The best match for each blip for starting new tracks are stored in the gain function. The tracker uses the algorithm from Stanford graph based package of Knuth [16] [51]. Figure 4-6 shows tracks created using the minimum distance criterion. Figures 4-7 and 4-8 are snapshots of sample data and tracks created by the nearest neighbor tracker plugin. User selectable parameters in the Nearest Neighbor model in radR are given in Table 4-2.
Figure 4-6: NN Model with track 1 created using the minimum distance
Figure 4-7: Sample data in radR

Figure 4-8: Snapshot of tracks created by the Nearest Neighbor Plugin in radR
Table 4-2: Parameters in the Nearest Neighbor model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min. Range</th>
<th>Max. Range</th>
<th>Recommended Values</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>How long a blip is retained as a possible track starter</td>
<td>1</td>
<td>3600</td>
<td>4</td>
<td>Time for retaining blips to find matches in scans.</td>
</tr>
<tr>
<td>How long track stays active after last blip</td>
<td>1</td>
<td>3600</td>
<td>10</td>
<td>Time to preserve a track in scans.</td>
</tr>
<tr>
<td>Maximum turning rate (degrees per second)</td>
<td>0</td>
<td>180</td>
<td>20</td>
<td>Turning rate is set to remove fast maneuvering targets.</td>
</tr>
<tr>
<td>Maximum rate of change of blip area (percent/scan)</td>
<td>0</td>
<td>300</td>
<td>150</td>
<td>Rate of change of blip area that are added to tracks.</td>
</tr>
<tr>
<td>Maximum rate of change of blip intensity (percent/scan)</td>
<td>0</td>
<td>300</td>
<td>150</td>
<td>Rate of change of blip intensity that are added to tracks.</td>
</tr>
</tbody>
</table>

4.3.2. Multi Frame Correspondence (MFC) Model:

False hypothesis helps in obtaining matches close to the predicted value which is similar to the NN. However, the direction of motion is not considered which gives rise to irregular paths [52]. The sample data and snapshot using MFC tracking in radR are shown in Figures 4-10 and 4-11 respectively. User selectable parameters in the MFC model in radR are given in Table 4-3. Tracks are stored in tracks.csv file with all the blip information. Parameters stored in this file are given in Table 4-4. A sample of tracks.csv file is shown in Table 4-5.

Dr. Jeremy Ross visually counted targets each night for a period of 10 minutes. This was done for both vertical and parabolic antennas. Outputs from radR were compared with
visual observations. Errors between two values were plotted. Plots were checked for their linearity. Blip parameters producing linear and minimum errors were then selected. A list of all required and selected parameters for blip processing and tracking building for the MFC tracker models is provided in Table 4-6.
Figure 4-9: Sample Data in radR

Figure 4-10: Snapshot of tracks created by Multiframe Correspondence Plugin in radR
Table 4-3: Parameters in MFC model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min. Range</th>
<th>Max. Range</th>
<th>Recommended Values</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of scans to backtrack</td>
<td>2</td>
<td>100</td>
<td>2</td>
<td>For each additional scan the tracks can be corrected by backtracking.</td>
</tr>
<tr>
<td>Weight of directional coherence Vs. proximity to prediction</td>
<td>0</td>
<td>1</td>
<td>0.5</td>
<td>Parameter is set to 0.5 as values &lt; 0.5 increases false targets and &gt; 0.5 has low detection rates.</td>
</tr>
<tr>
<td>Minimum gain of blips to be a part of a track</td>
<td>-150</td>
<td>150</td>
<td>10</td>
<td>A minimum gain value above which the blips are added to tracks.</td>
</tr>
<tr>
<td>Penalty for blips missing in tracks</td>
<td>0</td>
<td>1</td>
<td>0.001</td>
<td>This parameter is not used in the code and does not affect data.</td>
</tr>
</tbody>
</table>

Table 4-4: Parameters in tracks.csv file

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>scan no.</td>
<td>The scan number of the blip.</td>
</tr>
<tr>
<td>track no.</td>
<td>Each track is assigned a number.</td>
</tr>
<tr>
<td>date</td>
<td>Date of the data collected.</td>
</tr>
<tr>
<td>time</td>
<td>Time of occurrence of blip.</td>
</tr>
<tr>
<td>range</td>
<td>Range of target in meters.</td>
</tr>
<tr>
<td>x, y, z coordinate</td>
<td>x, y, z position of target in meters.</td>
</tr>
<tr>
<td>ns</td>
<td>Number of samples for each target.</td>
</tr>
<tr>
<td>area</td>
<td>Area of blip in square meters.</td>
</tr>
<tr>
<td>int</td>
<td>Mean intensity of blips.</td>
</tr>
<tr>
<td>max</td>
<td>Maximum intensity of the blip.</td>
</tr>
<tr>
<td>aspan</td>
<td>Number of rows of stats cell along angular region</td>
</tr>
<tr>
<td>rspan</td>
<td>Number of columns of stats cell along range.</td>
</tr>
<tr>
<td>perim</td>
<td>Perimeter of the blip.</td>
</tr>
</tbody>
</table>
Table 4-5: Sample Tracks.csv file

<table>
<thead>
<tr>
<th>scan.no</th>
<th>track.no</th>
<th>blip.no</th>
<th>date</th>
<th>time</th>
<th>timestamp</th>
<th>range</th>
<th>x</th>
<th>y</th>
<th>z</th>
<th>ns</th>
<th>area</th>
<th>int</th>
<th>max</th>
<th>aspan</th>
<th>rspan</th>
<th>perim</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>50</td>
<td>28</td>
<td>4/13/2012</td>
<td>3:04:10</td>
<td>1334286250</td>
<td>625</td>
<td>453</td>
<td>-399</td>
<td>162</td>
<td>33</td>
<td>178</td>
<td>0.703</td>
<td>0.918</td>
<td>13</td>
<td>7</td>
<td>92</td>
</tr>
<tr>
<td>33</td>
<td>50</td>
<td>181</td>
<td>4/13/2012</td>
<td>3:04:15</td>
<td>1334286255</td>
<td>645</td>
<td>499</td>
<td>-372</td>
<td>167</td>
<td>59</td>
<td>327</td>
<td>0.717</td>
<td>0.914</td>
<td>13</td>
<td>7</td>
<td>133</td>
</tr>
<tr>
<td>34</td>
<td>50</td>
<td>261</td>
<td>4/13/2012</td>
<td>3:04:17</td>
<td>1334286258</td>
<td>638</td>
<td>517</td>
<td>-336</td>
<td>165</td>
<td>38</td>
<td>209</td>
<td>0.648</td>
<td>0.831</td>
<td>13</td>
<td>8</td>
<td>130</td>
</tr>
<tr>
<td>35</td>
<td>50</td>
<td>325</td>
<td>4/13/2012</td>
<td>3:04:19</td>
<td>1334286260</td>
<td>643</td>
<td>526</td>
<td>-331</td>
<td>166</td>
<td>74</td>
<td>410</td>
<td>0.694</td>
<td>0.886</td>
<td>23</td>
<td>9</td>
<td>152</td>
</tr>
</tbody>
</table>
4.4. Summary:

There are currently two tracker models available in radR. They may produce different false alarm rates. The MFC tracker has lower false alarm rates than the NN model. The MFC tracking model is then selected for all radar data processing. Targets were also observed from the radar display system. Visually observed target tracks were compared with tracks produced by the MFC tracker model. Parameters giving least amount of error and producing linear error curve were then selected. These selected parameter settings will be used for all data processing for the entire migration period.
<table>
<thead>
<tr>
<th>Blip processing Settings</th>
<th>Parabolic Antenna</th>
<th>Vertical Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise cutoff</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Learning scans</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Update stats every scan</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Exclude blips from stats update</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Old stats weighting</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Hot score</td>
<td>2.8</td>
<td>4</td>
</tr>
<tr>
<td>Cold score</td>
<td>-128</td>
<td>-128</td>
</tr>
<tr>
<td>Samples per cell</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Pulses per cell</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Blips extend diagonally</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Blip centroids by area, not intensity</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Minimum blip samples</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Maximum blip samples</td>
<td>5000</td>
<td>5000</td>
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<tr>
<td>Minimum blip area (m²)</td>
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<tr>
<td>Maximum blip area (m²)</td>
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<td>50000</td>
</tr>
<tr>
<td>Minimum angular span</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Maximum angular span</td>
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<td>-1</td>
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<tr>
<td>Minimum radial span</td>
<td>6</td>
<td>-3</td>
</tr>
<tr>
<td>Maximum radial span</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>Also filter by logical expression</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

| Tracker controls Settings used           |                   |                  |
| Minimum number of blips required for a track | 4       | 4               |
| Maximum speed of tracked objects (km/h)  | 150               | 150             |
| Minimum number of blips before a track is plotted | 4       | 4               |
| How long to retain plots of complete tracks (s) | 30      | 30             |

<table>
<thead>
<tr>
<th>MFC control parameters:</th>
<th>MFC</th>
<th>MFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of scans to backtrack over in building tracks</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Weight of dir coherence vs prox to prediction</td>
<td>0.5</td>
<td>0.7</td>
</tr>
<tr>
<td>Minimum gain for blip to join track (log units)</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Small penalty for blips missing from tracks (gain units)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Chapter 5

Marine Radar Data Processing and Analysis

5. Marine Radar Data Processing and Analysis

The primary goal of this study was to collect information on the migration patterns of birds and bats crossing the lake during the peak period of Spring and Fall migration. Specifically, the objective of this study was to collect baseline information on flight direction, migration passage rates, and flight altitudes. This will help in identifying migration behavior with respect to lake crossing and other factors.

5.1. Study area

The Ottawa National Wildlife Refuge was established in 1961 to preserve habitat for migratory birds. Large numbers of migrating songbirds stop in this area to rest during their Spring and Fall migration. Our study included one marine radar sampling station located on the shores of lake Erie which provided a clear view of the surrounding area and was relatively unobstructed by trees. The sampling function has a clear line of sight for birds and bats in the area as shown in the Figure 5-2. Figures 5-2 to 5-4 provide other Google pictures to show selected radar site.

The vertical radar beam was oriented along north-south and east-west direction with sampling range of two nautical miles (nm). This orientation was changed depending upon
visual observation of direction of migration pattern of the birds thus the majority of 
migrating birds would be crossing the vertical beam. The parabolic antenna beam was setup 
with radius of three nautical miles. The beam width of the antenna was 3.5° at -3db power 
points. The angle of elevation of antenna was set to 15° to ground which resulted in an 
antenna surveying a cone shaped area of the sky. The maximum range for a small target to 
be detected is ~ .54 nm and the minimum detection range is 100 meters.

Figure 5-1: The highlighted position represents Ottawa National Park.
Figure 5-2: Google Maps view of the Radar site in Ottawa National Wildlife Refuge
Figure 5-3: Google maps view of radar site
Figure 5-4: Google maps view of radar site
5.2. Radar Equipment

The Furuno Model FR-1525 MKIII radar is a 25 kW standard commercially available marine radar transmitting at 9.410 GHz (X-band) through a 6.5 ft long slotted waveguide (antenna). Our marine radar was mounted on a trolley and that functioned as both a surveillance and vertical radar as shown in Figure 5-5. We also have a parabolic dish antenna with 60 cm diameter as shown in Figure 5-6. The radar with parabolic dish can be used as surveillance radar. It has a pencil beam and is able to suppress noise from the echoes of the waves.

The radar can be operated at a variety of ranges and pulse lengths. We used a pulse length of 0.07 µsec while operating most of the time at a 1 nm range. At shorter pulse lengths, echo resolution is improved thus giving more accurate information on target identification, location, and distance. Longer pulse length, improves echo detection and increases the probability of detecting a target. The output analog signal is collected and sent to a digitizing card. The data is stored onto a radar server (in our case a laptop).
Figure 5-5: Radar Trolley with Slotted antenna
5.3. Study Design

Dr. Jeremy Ross of the Bowling Green State University, Bowling Green, Ohio conducted nightly radar observations on 25 nights during the Spring 2011 (21 April to 25 May), 49 nights during the Fall 2011 (21 August to 25 October), 40 nights during the Spring 2012 (12 April to 27 May) and 42 nights during the Fall 2012 (24 August to 16 October) during the general peak period of migration in this region. Dates that data was collected for 2011 and 2012 are given in Table 5-1. This timing was chosen when it would be expected that many birds would be migrating through the area. On the remaining nights, he was unable to conduct radar observations because of inclement weather (rain).
Most of the nights the radar was used in vertical mode (i.e. antenna was placed in vertical position). He has also replaced the slotted antenna with a parabolic dish antenna in order to record information on flight direction, flight behavior, and passage rates of targets. The airspace sample covered by slotted and parabolic antennas are shown in Figure 5-7 and Figure 5-8.

The marine radar was operating all through the night from evening civil twilight to morning civil twilight. The data collection was divided into three time slots which were evening civil twilight, morning civil twilight and night time observations for Fall 2011 and Spring 2012. During this period parabolic dish was used during the night time to calculate the direction of the birds. During remaining time slots vertical radar was used to get a wider air sample range.
Table 5-1: Radar Data Collection Dates for Fall and Spring 2011 and 2012

<table>
<thead>
<tr>
<th>Spring 2011</th>
<th>Fall 2011</th>
<th>Spring 2012</th>
<th>Fall 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-May-2011</td>
<td>2-Sep-2011</td>
<td>18-Apr-2012</td>
<td>30-Aug-2012</td>
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<td>2-May-2011</td>
<td>4-Sep-2011</td>
<td>19-Apr-2012</td>
<td>1-Sep-2012</td>
</tr>
<tr>
<td>4-May-2011</td>
<td>5-Sep-2011</td>
<td>20-Apr-2012</td>
<td>3-Sep-2012</td>
</tr>
<tr>
<td>5-May-2011</td>
<td>6-Sep-2011</td>
<td>22-Apr-2012</td>
<td>5-Sep-2012</td>
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<td>7-Sep-2011</td>
<td>23-Apr-2012</td>
<td>6-Sep-2012</td>
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<td>9-May-2011</td>
<td>10-Sep-2011</td>
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<td>16-Sep-2011</td>
<td>1-May-2012</td>
<td>14-Sep-2012</td>
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<td>20-May-2011</td>
<td>17-Sep-2011</td>
<td>2-May-2012</td>
<td>15-Sep-2012</td>
</tr>
<tr>
<td>21-May-2011</td>
<td>18-Sep-2011</td>
<td>3-May-2012</td>
<td>16-Sep-2012</td>
</tr>
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<td>22-May-2011</td>
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<td>4-May-2012</td>
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<td>26-Sep-2012</td>
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<td>28-Sep-2011</td>
<td>29-Sep-2011</td>
<td>15-May-2012</td>
<td>30-Sep-2012</td>
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<tr>
<td>30-Sep-2011</td>
<td>30-Sep-2011</td>
<td>16-May-2012</td>
<td>1-Oct-2012</td>
</tr>
<tr>
<td>Date</td>
<td>Nights</td>
<td>Date</td>
<td>Nights</td>
</tr>
<tr>
<td>----------</td>
<td>--------</td>
<td>-----------</td>
<td>--------</td>
</tr>
<tr>
<td>14-Oct-2011</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>15-Oct-2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-Oct-2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17-Oct-2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18-Oct-2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21-Oct-2011</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>23-Oct-2011</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>25-Oct-2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27-Oct-2011</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-Oct-2012</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 5-7: Airspace sample by the marine Radar when operating in vertical mode

(antenna in the vertical orientation)
Figure 5-8: Airspace sample by the marine Radar when operating in parabolic mode
(parabolic antenna is used)

5.3.1. Vertical Scanning Mode – Target Counts and Altitudes

Vertical Antenna Radar Data X-band radar with a slotted waveguide antenna is operated vertical to the ground plane transmitting a wedge-shaped beam using a vertical scanning method [9]. Since the radar is rotated to its side, it scans a semi circled area through the atmosphere as shown in Figure 5-7. Radar digitizing card collects analog signal and converts them to digital signal which contains scan information extracted from the radar. Radar transmits radio waves with beam width of 20°, with a scan rate of ~2.5 seconds/scan, and can detect small targets with a size of birds. It can also detect bats up to 1 nm from the radar. X-band radar works at short wavelengths (3 cm); therefore interference from precipitation can be expected and during rain the data was not collected.
While using slotted T-bar antenna vertically, the data received will provide the target altitude. The data can then be used to determine the target passage rate through a given area.

The software records the altitude of those targets that are passing along or through the vertical antenna radar beam for each scan (rotation) of the radar (2.5 sec per rotation). The average altitude of each target was generated and used to derive the mean and median target heights. Targets are grouped targets into one of three categories: below rotor swept zone, in rotor swept zone, or above rotor swept zone to a maximum height of 1584 m. Migrating birds flying higher than 1584 m were not detected.

The industry standard for most migratory, wind energy avian studies and risk analysis is target detected per hour, The radar data was also normalized to target detected per hour. This data was normalized using the number of minutes that radar data was collected in a given time period. The time when radar was switched off because of rain was subtracted from the radar on period. The total number of targets detected per hour for the divided height zones and mean target altitudes were calculated.

5.3.2. Parabolic Scanning mode – Target Directions

X band radar with a parabolic dish antenna is operated in the horizontal plane transmitting a pencil shaped beam. In this configuration the radar with the parabolic
antenna is angled at 15° above the horizontal plane. It scans the atmosphere in a conical shape as shown in Figure 5-8.

The radar data collected using parabolic antenna was used to develop information on the movement of targets throughout the radar sampling area. As targets were detected on the radar, their bearing values were recorded on each scan of the radar. The average direction of the target is detected using the bearing of the target in each scan as target is detected in consecutive scans. The overall data is then plotted using Oriana Kovach Computing Services [53] to provide a directional assessment of the target movements throughout the sampling area. The data is also divided into different range categories and place categories such as land and water. The approach will help in determining the behavior of the detected targets on land and water.

5.4 Radar Recordings

Radar echoes are recorded using a 12-bit digitizing card. Each scan (for one complete rotation of antenna) will be stored in a separate file. Data from the radar is processed off-site using radR software package. Radar echoes recorded could be seen on screen in two ways; both as an unprocessed image by the Furuno radar (screen from the display of radar) and as a processed image by the radR software. They are shown in Figures 5-7 & 5-8.

Each recorded data has its own identification number. It was stored in the database with a file number according to sequence number of the scan. Sample file name will be sample*.REC (Samplexxxxxx.REC). Target data stored in databases are processed and
analyzed using R statistical package on windows based computer systems [45]. Different graphical representation of the data was developed as desired by wildlife biologists and radar ornithologists.
Figure 5-9: Sample of radar data in radR

Figure 5-10: Sampled radar data using blip filtering in radR
5.5. Data Analysis

Parameters stored in this file are given in Table 5-2.

Table 5-2: Parameters in tracks.csv file

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>scan no.</td>
<td>The scan number of the blip.</td>
</tr>
<tr>
<td>track no.</td>
<td>Each track is assigned a number.</td>
</tr>
<tr>
<td>date</td>
<td>Date of the data collected.</td>
</tr>
<tr>
<td>time</td>
<td>Time of occurrence of blip.</td>
</tr>
<tr>
<td>range</td>
<td>Range of target in meters.</td>
</tr>
<tr>
<td>x, y, z coordinate</td>
<td>x, y, z position of target in meters.</td>
</tr>
<tr>
<td>ns</td>
<td>Number of samples for each target.</td>
</tr>
<tr>
<td>area</td>
<td>Area of blip in meters.</td>
</tr>
<tr>
<td>int</td>
<td>Intensity of blips.</td>
</tr>
<tr>
<td>max</td>
<td>Maximum intensity of the blip.</td>
</tr>
<tr>
<td>aspan</td>
<td>Number of rows of stats cell along angular region</td>
</tr>
<tr>
<td>rspan</td>
<td>Number of columns of stats cell along range.</td>
</tr>
<tr>
<td>perim</td>
<td>Perimeter of the blip.</td>
</tr>
</tbody>
</table>

5.6. Processing of Radar data

The recorded radar data was stored on hard drives. The radR software uses recorded files as an input for further processing. The information from these files is plotted on a GUI window using XIR3000 archive plugin. Table 5-3 provides antenna settings used in the plugin. Figure 5-11 shows various antenna control settings. Examples of plots from vertical T-bar and parabolic antenna are shown in Figures 5-12 and 5-13.
Before starting the parabolic antenna radar, sample scans were taken with angle 0° elevations. Initial scans help in determining the true north for the parabolic data. The selected area in Figure 5-15 should be directly pointed upwards; therefore, the scan should be rotated towards true north.

The angle of true north is then used to calculate the corrected position values during post processing. Zone plugin for parabolic antenna should be a circle with 375 meters as its radius as shown in Figure 5-17 to avoid ground clutter. Zone plugin for vertical T-bar antenna should be half of the T-bar antenna data as shown in Figure 5-18 to avoid ground clutter.

Table 5-3: Antenna settings that need to be changed

<table>
<thead>
<tr>
<th>Values</th>
<th>T-Bar Antenna</th>
<th>Parabolic Dish Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of beam above rotation plane</td>
<td>0°</td>
<td>15°</td>
</tr>
</tbody>
</table>
Figure 5-11: Antenna controls

Figure 5-12: Example of vertical T-bar antenna
Figure 5-13: Example of Parabolic antenna

Figure 5-14: (a) Parabolic antenna with 0° elevation, (b) 15° elevation
Figure 5-15: Parabolic scan before rotating it towards true north

Figure 5-16: Parabolic scan after rotating it towards true north
Figure 5-17: Zone plugin for parabolic antenna

Figure 5-18: Zone plugin for vertical T-bar antenna
Table 5-4 shows the parameter setting for two the antennas. Dr. Jeremy Ross set these parameters based on comparison between the output of data generated by the radR and the real time observations during data collection process. Parameters with least error rate with the real time observations were chosen. The same parameters were used for processing of the data for spring and fall 2011-2012. The approach will allow comparison of data from different seasons and years.

<table>
<thead>
<tr>
<th>Blip processing Settings</th>
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<th>Vertical Antenna</th>
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<tbody>
<tr>
<td>Noise cutoff</td>
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<tr>
<td>Pulses per cell</td>
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</tr>
<tr>
<td>Feature</td>
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<td>Value 2</td>
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<td>Yes</td>
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<td>5000</td>
</tr>
<tr>
<td>Minimum blip area (m²)</td>
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<td>50</td>
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<td>50000</td>
</tr>
<tr>
<td>Minimum angular span</td>
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<td>3</td>
</tr>
<tr>
<td>Maximum angular span</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>Minimum radial span</td>
<td>6</td>
<td>-3</td>
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<tr>
<td>Maximum radial span</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>Also filter by logical expression</td>
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<td>No</td>
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</table>

Tracker controls Settings used

<table>
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<th>Value 1</th>
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<tbody>
<tr>
<td>Minimum number of blips required for a track</td>
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<td>4</td>
</tr>
<tr>
<td>Maximum speed of tracked objects (km/h)</td>
<td>150</td>
<td>150</td>
</tr>
<tr>
<td>Minimum number of blips before a track is plotted</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>How long to retain plots of complete tracks (s)</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

MFC control parameters:

<table>
<thead>
<tr>
<th>Feature</th>
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<th>Value 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of scans to backtrack over in building tracks</td>
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<td>Weight of dir coherence vs prox to prediction</td>
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</tr>
<tr>
<td>Small penalty for blips missing from tracks (gain units)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

5.7. Post Processing of Radar data

Processed radar data generates track files in .csv format. These .csv files are further processed to remove additional discrepancies. Following post processing protocol is used:
(1) The total number of blips in a given scan is calculated. If the blip count is more than 60 in a given scan then all blips from that particular scan are deleted. This is to filter out rain data from these scans.

(2) Tracks are split where jumps are greater than six seconds between subsequent blips in a track.

(3) Segment times are calculated as the duration between two consecutive blips in a track. Segment times greater than six seconds are filtered. This process is repeated until no more instances of segment times greater than six seconds are found.

(4) All eligible split tracks are assigned new names by concatenating a “b” to “track number.

For example if tracks are split in step 2 then there could be two different targets which are considered as a single target. If the split track is valid i.e. it’s a valid target, we assign a new name to the track by concatenating a “b” to track number.

(5) Tracks with less than four blips are deleted.

(6) Resulting data is then used to calculate different parameters to generate final results.

Following parameters are computed:

(1) Velocity of the birds: Total distance travelled by the birds divided by the time taken by the birds.

(2) Flight direction: Calculate the height variation of the birds i.e. if the birds are ascending or descending.
(3) Direction of the birds: Direction of birds is calculated using the x and y coordinates of the blips in the track. Each segment course direction is calculated with x and y for each segment of the track. Mean Sine and Mean Cosine values of the segment course are calculated.

(4) Mean course direction is calculated as:

\[ \bar{\mu} = \tan^{-1}\left(\frac{\bar{\sin}}{\bar{\cos}}\right) \]

(5) Place division: Detected birds are divided into two groups. First group is birds detected on water and the second group is birds detected on land. This division helps us in determining the variation in direction of birds on land and water. The approach may shed a light on behavior of birds when facing large body of water such as Lake Erie.

(6) Range division: Detected birds are divided into following four groups.

- Birds detected in range between 0 meters and 500 meters
- Birds detected in range between 500 meters and 1000 meters
- Birds detected in range between 1000 meters and 1500 meters
- Birds detected in range 1500 meters and higher

5.8. Results

Data was collected during fall and spring migration period of 2011 and 2012. Table 5-5 provides a list of graphs that were plotted on the advice of wild life biologists. Table 1.1 provides various seasons that data was plotted.
Table 5-5: List of collected parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>2011</th>
<th>2012</th>
<th>2011 and 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction of birds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction of birds on land/water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction of birds w.r.t range (0-500,500-1000,1000,1500,1500-)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction of birds on land/water w.r.t range (0-500,500-1000,1000,1500,1500-)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birds detected per hour t-bar/parabolic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean flight velocity t-bar/parabolic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean flight altitude t-bar/parabolic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birds detected on land/water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birds detected w.r.t range (0-500,500-1000,1000,1500,1500-)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birds detected on land/water w.r.t range (0-500,500-1000,1000,1500,1500-)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birds detected w.r.t flight direction (ascending/descending)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5-6: List of data collected and their season to season comparison

<table>
<thead>
<tr>
<th>Season</th>
<th>2011</th>
<th>2012</th>
<th>2011 and 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fall</td>
<td></td>
<td>Fall</td>
<td>Fall and Fall</td>
</tr>
<tr>
<td>Spring</td>
<td></td>
<td>Spring</td>
<td>Spring and Spring</td>
</tr>
</tbody>
</table>
Most nocturnal radar targets were travelling in seasonally appropriate directions for fall and spring migration.

![Direction of Birds in Spring 2011](image)

Figure 5-19: Direction of birds flying during Spring Migration 2011.

Figure 5-19 shows the direction of birds detected by the radar during Spring 2011. Birds are flying in northerly direction, with mean flight direction of 336.86° and circular standard deviation of 68.712°.
Figure 5-20 shows the direction of birds detected by the radar during Spring 2012. Birds are flying in northerly direction, with mean flight direction of 2.354° and circular standard deviation of 75.313°.
Figure 5-21: Direction of birds flying during Fall Migration 2011.

Figure 5-21 shows the direction of birds detected by the radar during Fall 2011. Birds are flying in southerly direction, with mean flight direction of $217.166^0$ and circular standard deviation of $70.822^0$. 
Figure 5-22: Direction of birds flying during Fall Migration 2012.

Figure 5-22 shows the direction of birds detected by the radar during Fall 2012. Birds are flying in southerly direction, with mean flight direction of $185.332^\circ$ and circular standard deviation of $68.031^\circ$. 
Figure 5-23: Flight directions in Spring 2011 on land with respect to different ranges.

Figure 5-23 shows the comparison of flight direction of the birds in Spring 2011 as they are approaching water for different ranges.
Figure 5-24: Flight directions in Spring 2011 on water with respect to different ranges.

Figure 5-24 shows the comparison of flight direction of the birds in Spring 2011 as they are travelling away from land for different ranges. Figures 5-25 to 5-28 show flight direction of birds flying during Fall 2011 and Spring 2012. Figures 5-29 to 5-35 show total number of birds detected per hour using T-bar and parabolic antennas and for different migratory seasons. Figures 5-36 to 5-41 show birds mean flight velocity in meters/second as determined by T-bar and parabolic antennas and for different migratory seasons.
5-42 to 5-48 show birds mean flight altitude in meters as determined by T-bar and parabolic antennas and for different migratory seasons.
Figure 5-25: Flight directions in Spring 2012 on land with respect to different ranges.
Figure 5-26: Flight directions in Spring 2012 on water with respect to different ranges.
Figure 5-27: Flight directions in Fall 2011 on land with respect to different ranges.
Figure 5-28: Flight directions in Fall 2011 on water with respect to different ranges.
Figure 5-29: Flight directions in Fall 2012 on land with respect to different ranges.
Figure 5-30: Flight directions in Fall 2012 on water with respect to different ranges.
Figure 5-31: Total number of birds detected per hour with vertical T-bar antenna during Spring 2011
Figure 5-32: Total number of birds detected per hour with parabolic antenna during Spring 2011
Figure 5-33: Total number of birds detected per hour with vertical T-bar antenna during Spring 2012
Figure 5-34: Total number of birds detected per hour with parabolic antenna during Spring 2012
Figure 5-35: Total number of birds detected per hour with T-Bar antenna during Fall 2011
Figure 5-36: Total number of birds detected per hour with parabolic antenna during Fall 2011
Figure 5-37: Birds detected per hour with parabolic for Fall 2012
Figure 5-38 : Birds mean flight velocity for T-Bar during Spring 2011

Figure 5-39 : Birds mean flight velocity for parabolic during Spring 2011
Figure 5-40: Birds mean flight velocity for T-Bar during Spring 2011

Figure 5-41: Birds mean flight velocity for T-Bar during Fall 2011
Figure 5-42: Birds mean flight velocity for parabolic during Fall 2011

Figure 5-43: Birds mean flight velocity for parabolic during Fall 2012
Figure 5-44: Birds Mean flight Altitude for T-Bar during Spring 2011
Figure 5-45: Birds Mean flight Altitude for parabolic during Spring 2011
Figure 5-46: Birds Mean flight Altitude for T-Bar during Spring 2012
Figure 5-47: Birds mean flight altitude detected using Parabolic Antenna in Spring 2012
Figure 5-48: Birds mean flight altitude detected using T-Bar Antenna in Fall 2011
Figure 5-49: Birds Mean flight Altitude for parabolic during Fall 2011
Figure 5-50: Birds Mean flight Altitude for parabolic during Fall 2012

Figures 5-51 to 5-54 show numbers of birds detected using parabolic antenna for different seasons with respect to land and water. It can be seen that more birds are on water during spring as they are migrating to North and crossing Lake Erie. Similarly more birds are on land during fall as they are migrating to South and have already crossed the Lake Erie. Figures 5-55 and 5-57 show total number of birds detected w.r.t range using parabolic antenna for Spring and Fall 2011 respectively. It can be seen that most birds were flying between 500 and 1000 meter range. Figures 5-59 to 5-64 show ascending and descending rates with different antennas and seasons.
Figure 5-51: Birds detected w.r.t Land/Water for parabolic in Spring 2011
Figure 5-52: Birds detected w.r.t Land/Water for parabolic in Fall 2011
Figure 5-53: Birds detected w.r.t Land/Water for parabolic in Spring 2012

Figure 5-54: Birds detected w.r.t Land/Water for parabolic in Fall 2012
Figure 5-55: Birds detected w.r.t range for parabolic in Spring 2011
Figure 5-56: Birds detected w.r.t range for parabolic in Fall 2011

Figure 5-57: Birds detected w.r.t range for parabolic in Fall 2012
Figure 5-58: Birds detected w.r.t flight direction with T-Bar in Spring 2011

Figure 5-59: Birds detected w.r.t flight direction with parabolic in Spring 2011
Figure 5-60: Birds detected w.r.t flight direction with T-Bar in Fall 2011
Figure 5-61: Birds detected w.r.t flight direction with parabolic in Fall 2011

Figure 5-62: Birds detected w.r.t flight direction with T-Bar in Spring 2012
Figure 5-63: Birds detected w.r.t flight direction with parabolic in Spring 2012

Figure 5-64: Birds detected on Land/ Water w.r.t Range with Parabolic in Spring 2011

126
Figure 5-65 : Birds detected on Land/ Water w.r.t to Range with Parabolic in Fall 2011

Figure 5-63 to 5-66 show total number of birds detected on land and water with respect to various range using parabolic antenna for different seasons. These graphs will help us to determine the variation of birds movement on land and water. Most birds are flying in the range of 500 to 1000 meters. This range is the normal altitude for migrating birds. The parabolic dish is rotating in the clockwise direction. It will detect more birds if they are flying right of the radar in the spring than the fall. The radar will also detect more birds if they are flying left of the radar in the fall than the spring.

Figure 5-67 show comparison of birds detected per hour using a T-bar Antenna during Spring 2011 and Spring 2012. It can be seen that more birds were detected in Spring 2012 than 2011. It is due to the fact that more nights of data was collected in 2012 than 2011.
Figure 5-66: Birds detected on Land/ Water w.r.t to Range with Parabolic in Spring 2012

Figure 5-67: Birds detected on Land/ Water w.r.t to Range with Parabolic in Fall 2012
Figure 5-68: Comparison of birds detected using a T-bar Antenna during Spring 2011 and Spring 2012
Figure 5-69: Comparison of flight directions during Spring 2011 and Spring 2012 where data is divided according to place of detection.

Figure 5-69 shows a comparison of birds detected during the Spring season of 2011 and 2012. This Figure also shows the comparison of movement of birds as they are moving from Land to Water during Spring 2011 & 2012. Figure 5-68 shows comparison of flight direction for Spring 2012. It can be seen that most birds are flying in northerly direction in Spring which confirms their actual flying direction.
Figure 5-70 shows a comparison of birds detected during the Fall season of 2011 and 2012. This figure also shows the comparison of movement of birds as they are moving from water to land during Fall 2011 & 2012.
Summary

This chapter described study area and dates that data was collected. Study area and data collection nights were selected by Dr. Jeremy Ross from wildlife point of view. Processing of radar data was explained and it was followed by post processing. Radar data was processed with radR software. Post processing was performed using R, Excel and Oriana’s circular statistic software. Results of the data processing was shown in terms of direction, number of birds detected, their ranges. Ascending and descending rates were also computed as they are important to wildlife biologists to determine the behavior of birds while crossing large body of water. Results are presented for Spring and Fall migration period of 2011 and 2012.
Chapter 6

Conclusions and future work

6.1. Conclusion

The goal of this thesis was to study the migration patterns of birds over Lake Erie. It will be a useful tool for wildlife biologists, wind turbine developers and policy makers. The use of radR software has helped us a lot in achieving our goals. We have successfully performed radar surveys for four seasons and obtained very good data.

Marine radar data was collected during the peak migration periods of Spring 2011 & 2012 and Fall 2011 & 2012. Both T-bar and parabolic antennas were used. T-Bar antenna was used for larger air sampling of birds. Parabolic antenna was used for determining the direction in which migratory birds are flying. This study was conducted during peak migration periods of birds.

We have managed to generate results similar to the results provided by commercially available radar systems available in the market. A new tracker model IMM filtering is also implemented. IMM is a popular tracking algorithm and also being used in commercially available radar tracking systems.
6.2. Future work

Velocity and noise levels change with time therefore implementation is challenging. NN data association is only used in these models, this can be improved with better techniques. False alarm rate can be reduced.
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142


Appendix A

Radar Data Collection, Processing and Analysis Procedure

Required software:

First digitizing card is connected to the radar through a slave port on radar and to the laptop computer through USB. Attached laptop computer should have following software:

- RadarSample software provided by Rutter Inc.
- Download radR software from radR-project.org
- Microsoft Office Excel
- Oriana circular statistic software from Kovcomp
- Download R statistic software from R-project.org

Collection of radar data:

Following steps are used for collection of data:

- Open RadarSample program (Rutter Inc)
- Select USB from Action menu option (Figure A-1 will be displayed)
- Start the radar
- Select Standby from Action menu option (Figures A-2 will be displayed)
- When radar starts recording then radar data will be displayed both on the radar display system Plan Position Indicator (PPI) and laptop duplicating from original radar display.
- Laptop will also display “settings” dialog box as shown in Figure A-3
- Click on “recording” button in the “setting” dialog box to start recording
• RadarSample program automatically creates a new folder with the name in the form of “date-time”. The recorded data for that period of scan is stored in that folder in the form of .rec files for each scan. These folder are saved on a hard disk and are brought to the laboratory for further processing. Folder will contain all files during this particular recording session.

Processing of radar data:

• Open radR software
• Use blip parameter setting as shown in Table A-1
• Select antenna from antenna plugin from radR
• Use XIR3000arch plugin to process .rec files
• Press play in radR to start processing one folder at a time.
• Files are processed one folder at a time using the xir3000arch plugin from radR.
• Output of the processed data will be an excel file. Name this file with same name as its processed folder name.
• Excel file will have data as shown in Table A-2
• Explanation of Excel data is provide in Table A-2
Figure A-1: Sample screenshot of RadarSample program
Figure A-2: Sample screenshot of RadarSample program
Figure A-3: Sample screenshot of Settings window

Blip parameter settings

Table A-1: Final list of Blip parameter settings

<table>
<thead>
<tr>
<th>Blip processing Settings</th>
<th>Parabolic Antenna</th>
<th>Vertical Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noise cutoff</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Learning scans</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Update stats every scan</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Exclude blips from stats update</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Old stats weighting</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>Hot score</td>
<td>2.8</td>
<td>4</td>
</tr>
<tr>
<td>Cold score</td>
<td>-128</td>
<td>-128</td>
</tr>
<tr>
<td>Samples per cell</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Pulses per cell</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Parameters</td>
<td>Comments</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>--------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>scan no.</td>
<td>The scan number of the blip.</td>
<td></td>
</tr>
<tr>
<td>track no.</td>
<td>Each track is assigned a number.</td>
<td></td>
</tr>
<tr>
<td>date</td>
<td>Date of the data collected.</td>
<td></td>
</tr>
<tr>
<td>time</td>
<td>Time of occurrence of blip.</td>
<td></td>
</tr>
<tr>
<td>range</td>
<td>Range of target in meters.</td>
<td></td>
</tr>
<tr>
<td>x, y, z coordinate</td>
<td>x, y, z position of target in meters.</td>
<td></td>
</tr>
<tr>
<td>ns</td>
<td>Number of samples for each target.</td>
<td></td>
</tr>
<tr>
<td>area</td>
<td>Area of blip in meters.</td>
<td></td>
</tr>
<tr>
<td>int</td>
<td>Mean Intensity of blips.</td>
<td></td>
</tr>
<tr>
<td>max</td>
<td>Maximum intensity of the blip.</td>
<td></td>
</tr>
<tr>
<td>aspan</td>
<td>Number of rows of stats cell along angular region</td>
<td></td>
</tr>
<tr>
<td>rspan</td>
<td>Number of columns of stats cell along range.</td>
<td></td>
</tr>
</tbody>
</table>

Table A-2: List of variables from tracks.csv
Post processing of data

Post processing of data requires created Excel file from the previous processing step. Following are post processing steps:

1. The total number of blips in a given scan is calculated. If the blip count is more than 60 in a given scan then all blips from that particular scan are deleted. This is to filter out rain data from these scans.

2. Tracks are split where jumps are greater than six seconds between subsequent blips in a track.

3. Segment times for each track are calculated. Segment times with greater than six seconds are filtered. This process is repeated until no more instances of segment times with greater than six seconds are found.

4. As mentioned in step 2, tracks are split because there could be two different targets which are considered as a single target. If the split track is valid i.e. it’s a valid target, we assign a new name to the track by concatenating a “b” to track number.

5. Tracks with less than four blips are deleted.

After the above filtering methods are applied, the final data obtained is used to calculate different parameters to generate final results. Following parameters are calculated:

(1) Velocity of the birds: Total distance travelled by the birds divided by the time taken by the birds.
(2) Flight direction: Calculate the height variation of the birds i.e. if the birds are ascending or descending.

(3) Direction of the birds: Direction of birds is calculated using the x and y coordinates of the blips in the track. Each segment course direction is calculated with x and y for each segment of the track. Mean Sine and Mean Cosine values of the segment course are calculated.

(4) Mean course direction is calculated as:

\[ \mu = \tan^{-1}\left(\frac{\sin \bar{\eta}}{\cos \bar{\eta}}\right) \]

(5) Place division: Detected birds are divided into two groups. First group is birds detected on water and the second group is birds detected on land. This division helps us in determining the variation in direction of birds on land and water. The approach may shed a light on behavior of birds when facing large body of water such as Lake Erie.

(6) Range division: Detected birds are divided into following four groups.

- Birds detected in range between 0 meters and 500 meters
- Birds detected in range between 500 meters and 1000 meters
- Birds detected in range between 1000 meters and 1500 meters
• Birds detected in range 1500 meters and higher

We have developed two methods to generate the above results.

1. Using an excel sheet
2. Using R program

Plots are generated using the post processed excel file as input to the R program.

Multiple codes have been written in order to generate the required plot.

Final post processed excel file is used as input to the Oriana circular statistic program to generate required circular plots. Several options to generate a circular plot are available in this program.