Affordable Avian Radar Surveillance Systems For Natural Resource Management And BASH Applications

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SUMMARY AND CONCLUSIONS

Affordable avian surveillance radar systems have been developed for Natural Resource Management (NRM) and bird air strike hazard (BASH) applications. The system design described herein demonstrates that affordable, commercial off-the-shelf (COTS) marine radars combined with COTS personal computers (PCs) and sophisticated radar processing software can meet system requirements. Real performance data obtained using the Navy's eBirdRad radar unit installed at Patuxent River Naval Air Station demonstrate a significant advancement in state-of-the-art bird detection and tracking. This provides the impetus for maturing the technology into fully operational systems.

1. *INTRODUCTION*

It is well recognized that for improved air safety, management of the air space in the vicinity of runways must account for bird activity in addition to planes, ground vehicles, and weather. However, affordable, near-range, radar systems capable of providing the required real-time, bird detection and tracking information do not presently exist. Military organizations such as the U.S. Air Force and Navy, as well as civilian organizations such as the Federal Aviation Administration (FAA) and Transport Canada have supported research and development activities to help overcome this shortfall. This paper describes an affordable, avian radar surveillance system that has recently been developed by the Navy's SPAWAR Systems Center (San Diego) in conjunction with the Radar Ornithology Laboratory at Clemson University (South Carolina), and with Sicom Systems Ltd. (Ontario, Canada). The experimental system, referred to herein as *eBirdRad*, has undergone testing at the Patuxent Naval Air Station, Maryland, and has demonstrated state-of-the-art performance. While further research, improvements, and testing are necessary before full operational use can occur, the avian radar surveillance system design and its underlying technologies are well suited for the production of affordable avian radars that address the bird management problem.

2. *APPLICATIONS*

Air strikes such as the C-130 bird strike shown in Figure 1 cost in excess of one billion dollars annually in both damage to aircraft and interruptions of air operations worldwide. More importantly, every air strike also has the potential for loss of life. In September 1995, an Air Force E3 AWACS aircraft crashed after colliding with a flight of geese following take off from Elmendorf AFB in Alaska. All 24 occupants aboard the airplane were killed. Clearly, anything that can be done to reduce fatalities and property damage is of the highest priority to the operators of military and civilian aircraft alike. The following factors contribute to an increasing trend in bird strikes:

1. An increasing number of flights by military, commercial, and civilian aircraft,
2. Encroachment onto airfields of birds due to habitat loss elsewhere, and
3. Expanded distribution of migratory species such as the Canada Goose.

Additionally, many bird-aircraft collisions occur at dusk and dawn, when visual detection of the birds is difficult.

Figure 1: C-130 bird strike – Courtesy U.S. Navy NAS Patuxent River, MD.

Studies have been undertaken to detect both large-scale migratory patterns of birds using WSR-88D ("NEXRAD")

Doppler weather radars and regional bird activity using airport surveillance radars. These radar systems have an effective range of 30-60 nautical miles (nmi) and 6-30 nmi, respectively [1]. Until recently, there were no radar systems available to reliably detect and track bird activity at or near the airfield, in the 0-6 nmi range, where bird strikes are most likely to occur during take-off or landing.

The Natural Resources Program provides oversight and management of natural and environmental resources on Navy installations in accordance with DoD Instruction 4715.3. The responsibilities of Navy Natural Resource Managers (NRMs) include implementing and monitoring natural resources projects, developing, updating and implementing integrated natural resources management plans (INRMPs), negotiating with external agencies, providing legal compliance, and reviewing, interpreting and applying laws and regulations applying to natural resources and the environment.

The Department of Defense's (DoD) Legacy Program funded Dr. Sidney Gauthreaux of the Clemson University Radar Ornithology Laboratory to develop the BirdRad radar as a tool to measure bird activity in a 0-6 nmi radius around military bases; and in particular, around airfields. The goal of collecting these measurements was to better understand the diurnal and seasonal activity of migratory birds at these facilities. Each active DoD airfield has a BASH Program. BASH Coordinators, who are typically also NRMs, are responsible for reducing collisions between aircraft and wildlife, including birds. Thus, it quickly became apparent to BASH Coordinators that a 0-6 nmi bird radar could serve the dual purpose of studying and managing bird populations at their facilities and using this information to also reduce bird air strikes. With an enhanced BirdRad, or eBirdRad, the requirements of NRM and BASH Coordinator can be satisfied. The core requirements of eBirdRad center on automatic detection and tracking of birds in real-time. Following a competitive bid process, Sicom Systems Ltd. joined the SPAWAR/Clemson team to address these core requirements. In September 2004, acceptance tests were successfully carried out with a developmental eBirdRad unit at the Patuxent River Naval Air Station in Maryland [2].

3. *AVIAN RADAR SYSTEM DEVELOPMENT*

The development of an affordable avian radar system is described in the remainder of this paper. In Section 3.1, system requirements are discussed, followed by a system design to meet those requirements in Section 3.2. Section 3.3 presents a developmental eBirdRad unit that has been built in accordance with this design. Experimental results obtained from the developmental unit during bird activity at Patuxent River Naval Air Station are presented in Section 4, followed by a discussion of future work in Section 5.

3.1 *System Requirements*

The following key system requirements guided the design of eBirdRad:

- Radar coverage: 0 - 6 nmi, 360° azimuth
- Useful height information obtainable from bird targets
- Real-time radar operator's display to visualize bird targets and easily determine their locations
- Real-time automatic detection of bird targets with reliable detection of birds from small passerines to large raptors
- Real-time automatic tracking of bird targets, providing current location (latitude, longitude and altitude) and dynamic (speed and heading) estimates
- Ability to store raw radar signal data and processed detection and tracking data for off-line reprocessing
- Ability to output track data in real-time as a Web Service to other applications such as database management systems, in support of client access to data
- Geo-spatial visualization of bird tracks so that bird activity can be studied relative to wetlands, vegetation, buildings, etc..
- Portability - the ability to easily move the radar to different sites at a facility, or between facilities
- Remote control of the radar
- Scheduling of radar operation
- System tolerant to continuous operation in civilian and military air strip environments
- Affordability, in order to allow deployment at numerous military and civilian air strips

3.2 *System Design*

Satisfying the aforementioned requirements is very challenging. To allow for widespread deployment, a system cost on the order of $100,000 per unit is a design goal. While X-band or S-band coherent radar technology used in air traffic control and military radars could be integrated, reconfigured and optimized to satisfy performance requirements, such systems would not be affordable. A COTS approach has been adopted to leverage technology developed for a variety of other applications, thereby minimizing specialized component development and cost. A summary of key design elements follows.

The radar sensor is a COTS, noncoherent, marine radar with enough power and aperture for detecting and spatially localizing small birds. A Furuno Model 2155BB marine radar was selected. With its 50 kW peak power at X-band, and range resolution on the order of 10 m, it is well-suited for detecting small (and large) birds in the 0-6 nmi range. While a typical T-bar antenna (i.e. slotted waveguide antenna array) could be used to provide complete volume coverage, it provides poor altitude estimates (due to a large 20^0 elevation beamwidth). The standard antenna has been replaced by a parabolic antenna with 4° pencil beam in order to provide better altitude information. The trade-off is volume of coverage as illustrated in Figure 2. However, the antenna can be inclined in elevation to match the volume coverage needed during take-off and landing, or for sampling bird migration. A more expensive antenna could (in the future) be developed to provide for complete volume coverage and height information simultaneously (see Section 5). The Furuno 2155BB is also well suited for remote control of the radar set (Section 5).

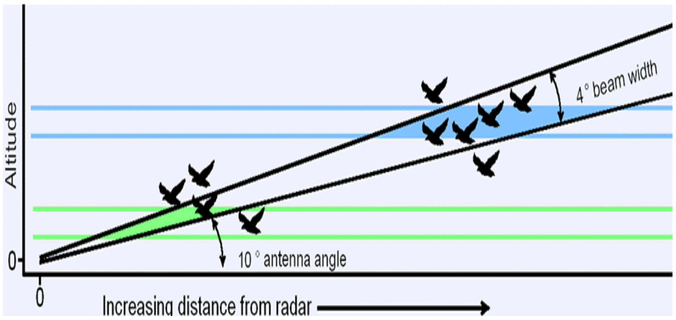

Figure 2: 4° pencil beam can be used to provide useful height information of detected birds.

The radar system is housed in a field-deployable trailer containing the radar, the radar controls, the eBirdRad processor and GPS. The antenna is mounted on the roof of the trailer, and its elevation angle is adjustable. Elevation is typically set between 0° and 30° above the horizon, depending on the intended use. The trailer is temperature controlled, includes its own power generation for continuous operation, and houses the operator's workstation. A prototype developed at SSC Charleston, is shown in Figure 3 and is of a form factor that can be towed or airlifted to operational locations.

Figure 3: Prototype eBirdRad trailer (antenna removed).

The eBirdRad processor is based on Sicom's Accipiter™ radar processor recently developed for homeland security applications [3] and modified for avian radar applications. A 12-bit, digital radar interface board plugs into the PCI slot of an off-the-shelf, Pentium4 PC. The radar interface digitizes each raw radar sweep and provides the data to the radar processor which carries out all radar signal processing, display, automatic detection, tracking, data archiving, and data distribution using Accipter's™ real-time software.

The radar processor includes radar signal processing functions such as scan-conversion, adaptive clutter-map processing to remove ground and weather clutter, sector blanking, constant false alarm rate (CFAR) detection, and numerous operator displays as illustrated by the figures presented in Section 4. In addition, a bird trails mode has been developed that retains current and past bird echoes and presents them as a fading trail, in order to make bird radar signatures easily visible to an operator. Low detection thresholds are used as proposed in [3] to increase the sensitivity of the radar, allowing smaller birds such as passerines to be detected. An unwanted side effect is that the false alarm rate increases substantially making it more difficult for tracking to perform. To mitigate this effect, as well as to successfully track through bird maneuvers without degradations in track quality, the radar processor includes multiple hypothesis testing (MHT) tracking with interacting multiple model (IMM) extended Kalman filtering.

The eBirdRad processor stores raw data and processed detection and tracking data in accordance with operator selections. The raw data recordings support off-line playback, reprocessing and analysis. The processor supports continuous writing of both detection and track reports directly to a database for post processing, interaction with geographical information systems (GIS), and for Web Services. The processor architecture supports real-time communication of track reports to remote sites using low bandwidth, COTS data channels (wired or wireless). Since the track reports contain all of the important target data (date, time, position, dynamics, size), remote situational awareness for BASH and NRM applications is easily realized.

The radar processor is a multi-threaded, C++ application designed for Windows® operating systems. As such, open Windows® networking protocols are available for exploitation. This allows the radar processor to be remotely controlled from anywhere on an established network, using COTS software (e.g. virtual network server and client software). A specially developed software application program interface (API) is used by the processor to directly control features on the radar set. Features such as power-on/off, transmit/standby, and waveform selection are controllable.

Scheduling of radar operation (especially for NRM applications where sampling at dusk and dawn can be inconvenient) is straightforward and can be designed either as an integrated API or using external software scripting techniques.

3.3 Experimental System Development

A developmental eBirdRad radar unit has been built and tested at the Patuxent River NAS in September 2004. The purpose of this unit is to validate the system design as well as to serve as a platform for further improvements. This experimental version employs a lower-cost version of the mobile trailer and contains the Furuno 2155BB radar with the modified parabolic antenna on a cart configuration as illustrated in Figure 4.

The radar antenna is mounted on a cart, approximately 5 feet off the ground. The antenna angle is typically set between 5°-10° above the horizon to survey near-ground activity, while higher tilt angles (as high as 30°) are used for overhead migration sampling. The radar can also be raised to mitigate blockage and resulting blind zones. The eBirdRad processor along with GPS, tower radios and other equipment are all mounted within the trailer.

Figure 4: Experimental radar cart configuration.

The experimental eBirdRad processor includes all of the design features described in Section 3.2, excluding those features listed in Section 5.

4. *EXPERIMENTAL RESULTS*

Preliminary performance results obtained using the developmental eBirdRad radar unit for experiments carried out at Patuxent River NAS in September 2004 are very encouraging. Some of these results are presented below. While more developmental and experimental work is needed to rigorously establish the performance characteristics of these avian radars, and to develop operating procedures for their use, the availability of high performance, affordable avian radars for NRM and BASH applications is clearly within reach.

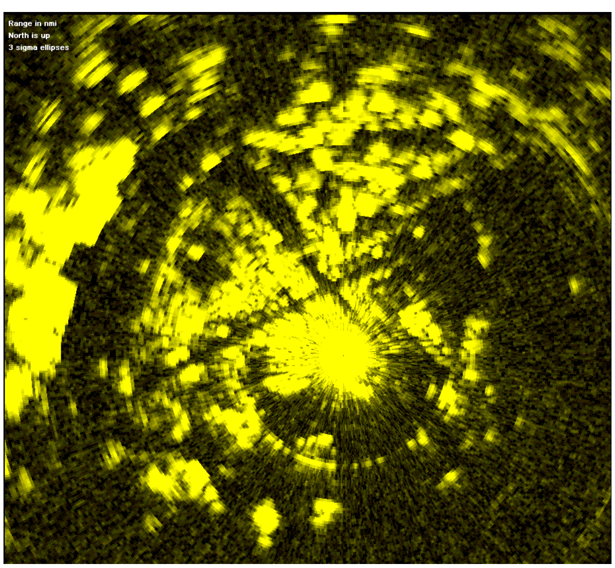

Figure 5: Unprocessed PPI display – 1 nmi radius

Clutter removal is a necessary radar signal processing function for reliable bird detection and tracking. Figure 5 illustrates an unprocessed plan position indicator (PPI) view of the radar echoes for the case where the antenna was raised 20 feet off the ground and pointed at the horizon. Two runways are clearly visible (the radar is located near their intersection); and clutter from adjacent fields, forests and buildings dominate the display. If a clutter map is used to suppress ground clutter, Figure 6 results. Residual radar echoes due to moving targets such as birds, ground vehicles, and aircraft survive. Three bird targets are easily identified in Figure 6 as a result of the trails processing algorithm that displays echoes from the current scan in one color, and echoes from previous scans in a second color that fades with time. With a little experience, bird target signatures can be readily distinguished from other targets.

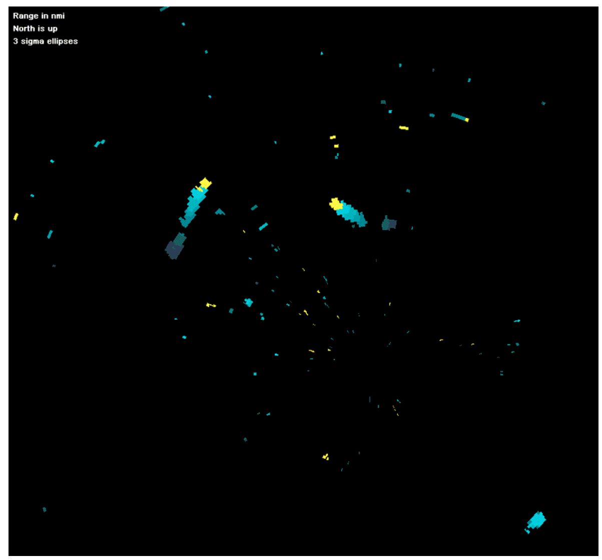

Figure 6: PPI display with clutter removed and bird trails on

In Figure 7, the unprocessed PPI display is shown during evening migration on 23 September 2004. The radar/antenna was operated on the cart on the ground this time, and the antenna was tilted up 30^{o} to sample higher altitude birds while reducing mainbeam ground returns. Sidelobe clutter dominates the display in this configuration and produces the circular-like patterns due to large structures (e.g. buildings, towers, trees) that are illuminated by the antenna sidelobes. These returns make reliable bird detection impossible. With clutter suppressed and trails processing employed, Figure 8 results. The largely southerly migration of numerous birds is now easily discerned from the display. If automatic detection and tracking algorithms (as described in Section 3.2) are now applied, Figure 9 results. Detections are indicated by small circles at the location where the clutter-map threshold was exceeded. A history of detections from the ten previous scans is shown with fading intensities indicating scan time (the current scan's detections are the brightest). Tracks are indicated by a square symbol (drawn at a target's current position) with a line emanating from the square (pointed to the direction the target is heading). By comparing Figure 9 with Figure 8, one can easily see that the detection and tracking algorithms are performing well.

Detection and track reports rich with target attributes are available to the operator in real-time. These reports are continuously streamed to a database used for archival as well as for remote communication. A real-time operator's display where target data are overlaid onto a facility map (Figure 10) enables target behavior to be more easily understood. The operator can select any track on the screen and the system will display target information such as position, speed, heading, track stage, track uncertainty, echo size and intensity, etc.. These target attributes can also be used for the study and classification of targets of interest, and for multi-sensor fusion.

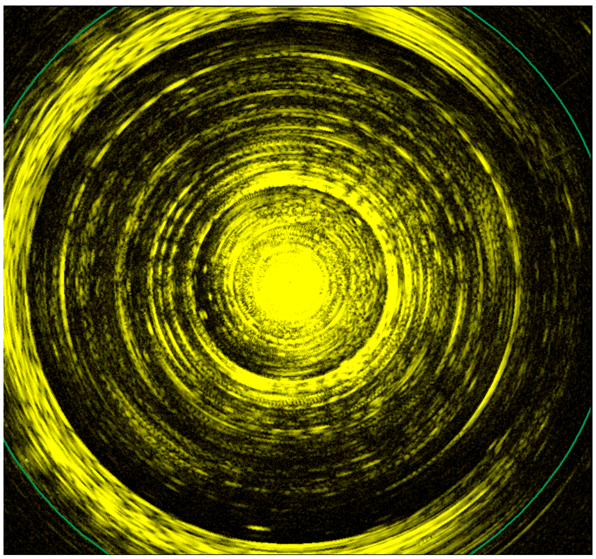

Figure 7: Unprocessed PPI display

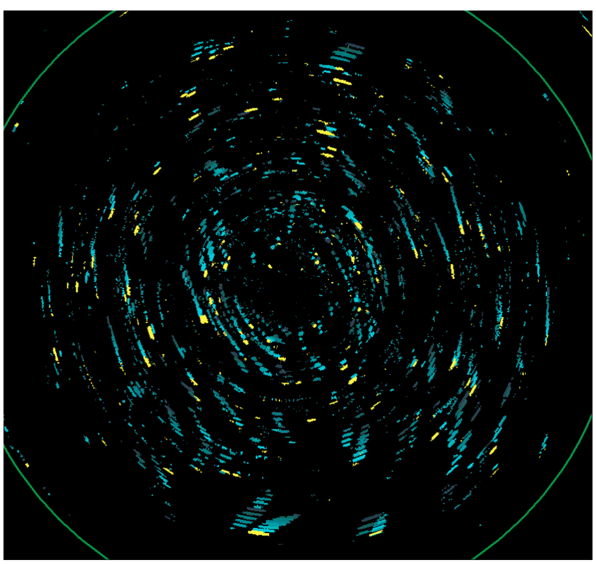

Figure 8: PPI display with clutter removed and bird trails

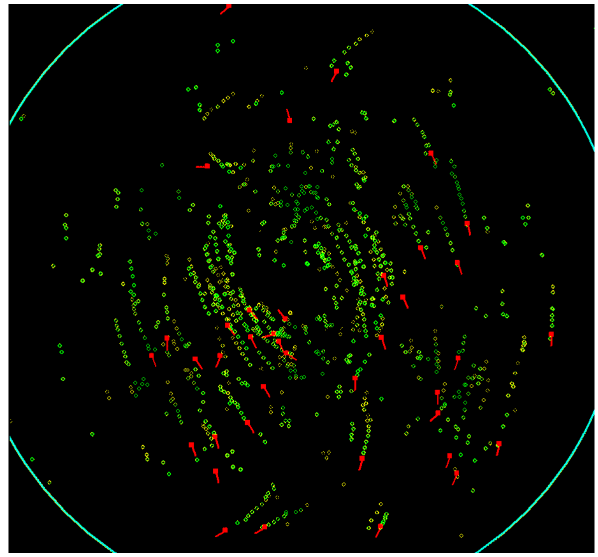

Figure 9: Automatic bird detections and tracks.

5. *FUTURE WORK*

Several of the design features described in Section 3.2 are either still under development or are slated for future development. These features are included in the following list of future work items:

- Development of radar set API
- Interaction with user and radar community including comparative testing with other systems.
- Development of automated scheduling to facilitate an extensive experimental campaign.
- Experimental campaign to rigorously evaluate performance and to report results to radar and avian researchers and to user community for their input.
- Development of GIS and Web services applications for dissemination of radar data to user / research community.
- Development of an optimized and affordable antenna system to provide good azimuth and elevation localization simultaneously, without sacrificing coverage. While 2D phased arrays have been given some consideration, the ideal solution may be a conventional, horizontally scanning antenna where high-resolution elevation estimates are achieved through the use of monopulse techniques.
- Integration of eBirdRad's processor and ancillary equipment with the field-deployable mobile trailer facility.
- Rigorous testing of eBirdRad's fully-integrated mobile radar system

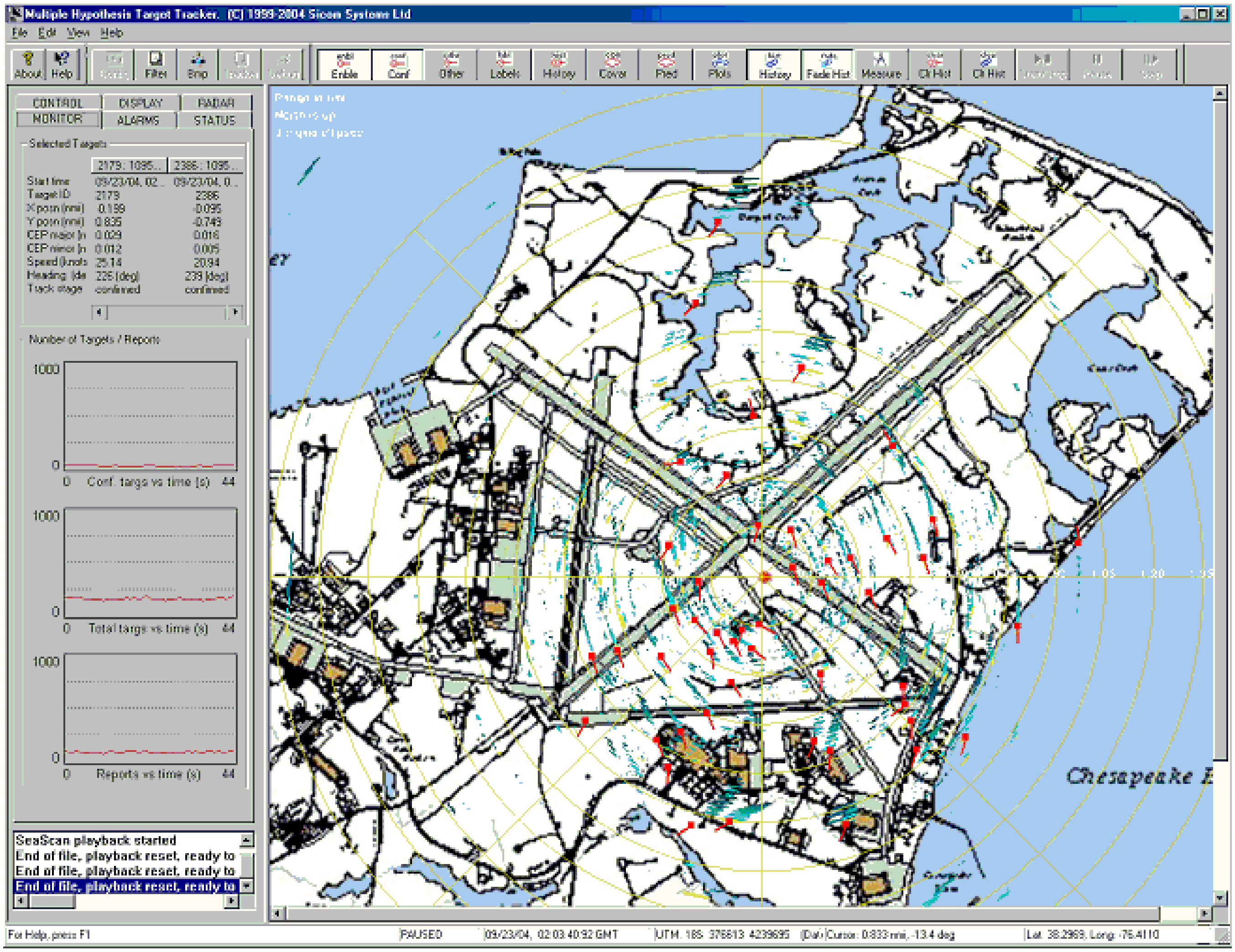

Figure 10: Operator's display during bird migration on 23 September 2004 with several bird targets overlaid on base map.

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BIOGRAPHY

Tim J. Nohara received the B.Eng degree from McMaster University in 1985, followed by the M.Eng and Ph.D degrees in 1987 and 1991, respectively, all in Electrical Engineering. He is the founding President of Sicom Systems Ltd., is a licenced professional engineer in Ontario, Canada, and is a member of the IEEE. His recent research interests are in the areas of system design, and signal and data processing applied to affordable radar solutions for avian radar and homeland security applications. He is the author of numerous technical publications, reports and patents.