Intelligence Based Tracking for Two Radar Applications

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Abstract

Intelligence based tracking is an integral part of the advanced radar design, with the purpose to maximize the probability of a wanted track whilst minimizing the probability of an unwanted or otherwise erroneous track. It can be implemented in many ways, among which are the following techniques: Track Quality Tracker (TQT), Map Aided Processing (MAP), Classification Aided Processing (CAP) and Track Retrodiction Tracker (TRT). We present results of these intelligence based techniques for two radar applications: high frequency surface wave radar (HFSWR) and air traffic radar (ATC). Performance improvements are evaluated by both Monte Carlo simulation and real radar data collected in trials. As a result of the desirable enhancements, these techniques already have been implemented in commercial radar products.

Introduction

The coastal nations' sovereign over their 200 nautical miles (nm), Exclusive Economic Zone (EEZ) drives the requirement for persistent surveillance. The need to provide continuous surveillance of shipping activity out to and beyond the EEZ led to the development of the high frequency surface wave radar (HFSWR). Canada has been investigating the use of HFSWR for persistent surveillance of the EEZ for more than 20 years. Early development cumulated in 2003 with the deployment of two SWR-503 HFSWR systems for monitoring the economically significant Grand Banks region on Canada's east coast.

Although successful, the system caused interference to the local radio communication systems and the technology was blocked from operation. At the same time, Raytheon Canada Ltd (RCL) started the development of their next generation HFSWR to address observed issues associated with the SWR-503 system. Primary design requirements included being a modular and scalable architecture, having the ability to support wideband operation, and to be compatible with other users of the HF spectrum.

This last requirement led to the development of a new power amplifier design that resulted in a constrained bandwidth and ultra-low spectral side-lobes. The new generation radar also included an enhanced spectrum management and reduced real estate requirements all at a low-cost. In 2011, RCL was awarded the contract to design and build the 3rd Generation HFSWR system for Persistent Active Surveillance of the EEZ (PASE). This new generation HFSWR would be installed and demonstrated at a site located near Halifax, Nova Scotia.

Figure 1: The 3rd Generation HFSWR [1].

Now the HFSWR becomes a demonstrated technology that offers persistent, “near” real-time surveillance of the EEZ such that patrol and response assists can be vectored to specific targets of interest, enabling interceptions well outside territorial waters. In this manner, HFSWR systems have been proven to be a significant sensing enabler for customers by allowing other mobile systems to be optimally deployed and tasked.

Air Traffic Control (ATC) Radar

There are many different models of ATC radars, typically in S or L band. For example, the ASR-11 Digital Airport Surveillance Radar (DASR) is a terminal area radar, providing primary surveillance radar (PSR) coverage to 60 nautical miles, and monopulse secondary surveillance radar (MSSR) coverage to 120 nautical miles [3]. The ASR-11 radar is manufactured by RCL.

Figure 2: Raytheon ATC Radar Facility [4].

Its basic system parameters are as follows:

- Frequency: 2,700 to 2,900 MHz (1 MHz steps)
- Pulsewidth (long): 89 µsec (long), 1 µsec (short)
- Pulse compression ratio: 89:1
- Antenna gain: > 33.5 dB
- Azimuth beamwidth: 1.40 degrees
- Polarization: Linear and circular
- Antenna rotation rate: 12.5 rpm
- Coherent processing interval: 5 pulses
- Subclutter visibility: > 42 dB
- Instrumented range: 60 nautical miles
- Target tracking capacity: > 1,000 targets
- MTBF: > 40,000 hours per channel
- Availability (PSR and MSSR system): 99.999 percent

Tracking Issues Observed in the Above Two Radars

HFSWR: The radar has been tested and evaluated through many real time trials. From those exercises, we have observed that the radar suffers from heavy unpredictable ionosphere, particularly at night, and sea clutters. The radar tracker has been severely challenged. Track duplication, track break-up and track seduction in scenarios involving manoeuvring targets, or high clutter/target environments are top issues and enhancements are needed [5].

ATC Radar: In the past decade or so, many countries have launched programs to deploy wind turbines as alternative sources of electrical energy. When deployed in wind farms, both ATC and military authorities have raised concerns on radar performance. This is due to the fact that the turbine blades return radar echoes that have the potential to distract and confuse the air traffic picture by creating false detections that can effectively mask genuine aircraft returns [6].

Most of the radar mitigation solutions offered today are either primarily based on such measures as range-azimuth gating or inhibiting track initiation in the vicinity of wind farms. These draconian measures can result in a significant degradation in radar performance and potential air traffic control disruption. They may also require costly redesign of the existing radars.

Intelligence Based Solutions

At the post detection stage, an improvement in performance in the presence of clutters can be achieved by using enhanced data association and tracking algorithm, two basic elements of a radar tracker. In this paper, we present four techniques that were studied and implemented for the two radar applications.

Track Quality Tracker (TQT): This technology was designed specifically for complicated and stressing scenarios of dense clutter environments. We use target features to formulate a new track quality based algorithms. Various embodiments are described for a track quality based multi-target tracker. The method includes associating a measurement with a track, generating measurement association statistics for the track, generating and updating a track quality value for a track based on a measurement-to-track association likelihood, and updating track lists based on the track quality value and the measurement association statistics of the tracks in these lists. The tracker includes structure for carrying out this method [7].

Map Aided Processing (MAP): In dense clutter regions, a more stringent gating based on assumed target motion dynamics can be used for track initialization and track association to decrease the overwhelming correlation options. An extreme situation is that no new tracks will be allowed in very dense clutter region where plots are only processed for association with confirmed tracks. Plot density map is generated using real radar data from the same site. The map is smoothed when limited data is available. The map is then incorporated into the tracker in the following six places [6]: gate distance size factor; angle gate of yes or no; potential track gate of yes or no; number of coasts for a track; potential track initialization of yes or no

We also use maps to generate adaptive track promotion logic. When adaptive promotion logic is utilized, the above numbers are adjusted based on the clutter distribution, resulting is a significant reduction in both false track and dropped track rates.

Classification Aided Processing (CAP): This has been implemented via classifier-aided tracking based on Support Vector Machines (SVM) technique for track classification [6]. A classifier-aided tracker has then been implemented by RCL. As shown in [4], it yields considerable improvements in the presence of wind farms with respect to the conventional tracking techniques. A multi-feature classifier aided tracker was implemented to evaluate its effectiveness. This classifier brings all available features into one unified function which is directly used for data association purpose [7].

Track Retrodiction Tracker (TRT): Track retrodiction is an additional processing on top of the traditional track estimation. Typically, a retrodiction window length L is specified. During the retrodiction, all track states are “re-estimated” based the traditional track estimates and some “future” measurements within a pre-selected time window. In other words, two steps, track estimation and track retrodiction, are involved [8].

Performance Evaluation Using Monte Carlo Simulation and Real Radar Data

In the simulated scenario, 5 targets are considered (Figure 3). Each target performs at least one coordinated turn. The number of false alarms corresponding to the sensor per scan is Poisson distributed. The false alarms are uniformly and independently distributed in range, azimuth angle and range rate. As a result, the false alarm density is higher at lower values of the range.

Table 1 shows performance metrics for two trackers obtained by averaging over 100 MC runs. It can be seen that the track quality-based tracker performs better in all performance measures. Consistent success is achieved particularly in increasing the percentage of target trajectory tracks and in reduction of the average false track lifetime.

This shows that the tracker improves track continuity and at the same time decreases average false track length. The results show that the new tracker can decrease the average false track length and extend the track life significantly in scenarios where the probability of track detection is low. Furthermore, the number of false tracks does not increase with the tracker even if the clutter density is high.

Real data from HFSWR radar shows that occasionally a target may not be visible for a number of scans (Figure 4). To include this possibility in the simulation, the detection event is considered to be the result of two processes. At each scan, the first process can start a sequence of missed detections corresponding to a target with a probability of 0.05. The length of each missed detection sequence is a Poisson random variable with an average of 8. In any scan, if a missed detection sequence is not active for a particular target it can still be missed with probability of 0.15.

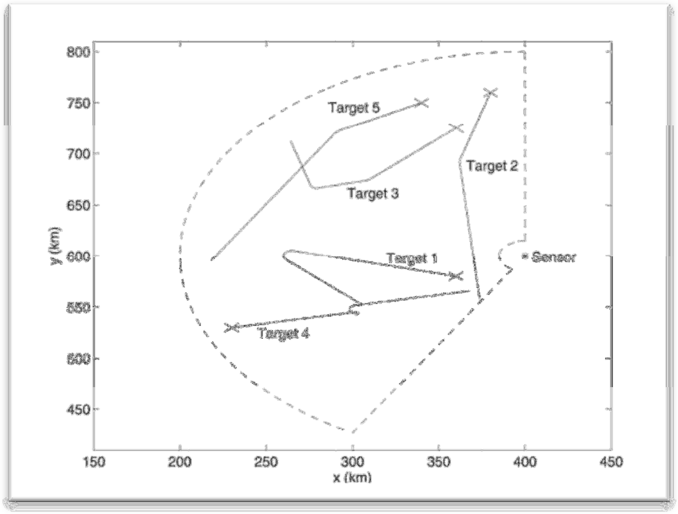

Figure 3: HFSWR Simulation Scenario for the Evaluation of the Track Quality Tracker.

Table 1: Performance Comparison by Simulation

Algorithm	Detection Delay (min)	% of Traj. Tracked	Position RMSE (m)	Velocity RMSE (m/s)	Avg. False Track no./run	Avg. False Track Life (min)
Track Quality	10.12	82.2%	940.7	2.42	1.61	14.02
Fixed logic	10.59	74.6%	987.4	3.02	1.78	24.38

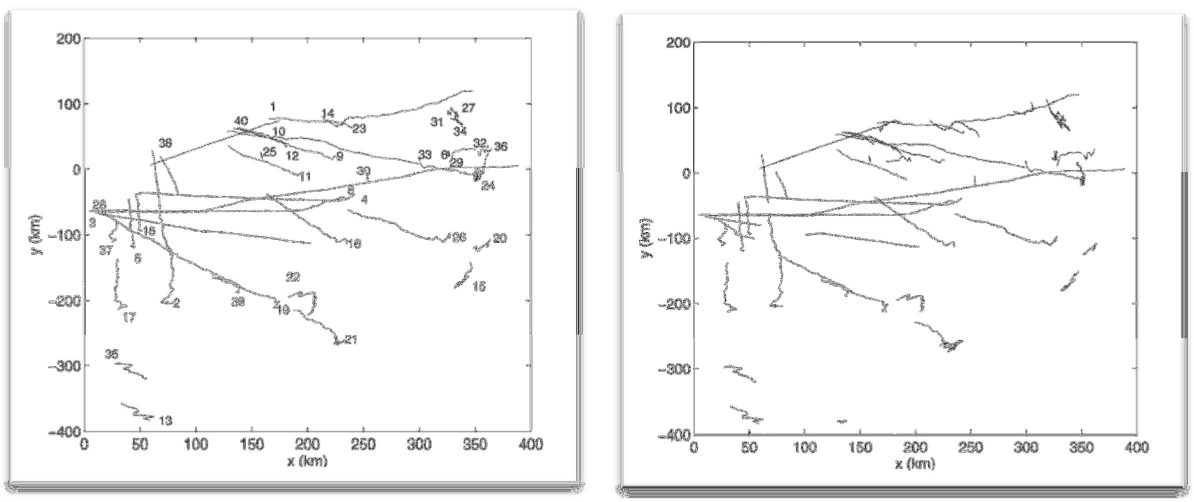

Figure 4: Track Picture of Track Quality Tracker vs Fixed Logic Tracker with Real Radar Data.

For the technique MAP, a comparison between non-adaptive and adaptive track promotion logic is presented in Figure 5. The figure present tracks of vessels as observed from an HFSWR in range-time coordinates. It can be observed that a large number of false tracks occur 30 to 40 km off shore. These tracks are associated with local clutter conditions in the region that results in a high density of plots that the non-adaptive tracker associates into false tracks and also results in track seduction. Using adaptive track promotion logic based on the sensed environment eliminates the vast majority of the false tracks.

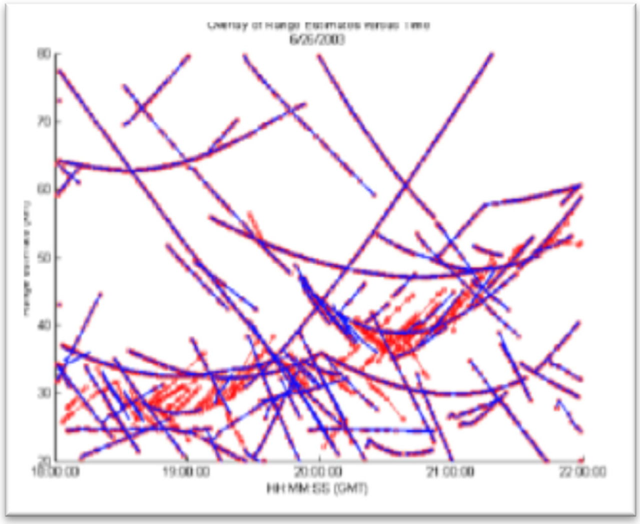

Figure 5: Comparison of Non-Adaptive and Adaptive Track Promotion Logic.

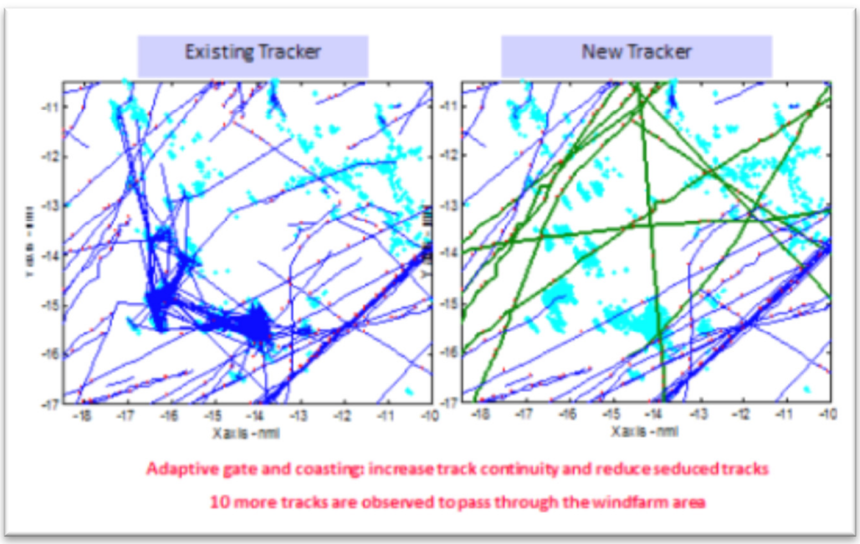

Figure 6: Track Picture Using Adaptive Gate and Coasting.

The technique CAP makes use of a classifier for classifying targets detected by radar and sonar systems. An exemplary embodiment of a classification system is given for ATC radar discriminating between aircrafts and non-aircrafts targets (Figure 7). This classification may be generalized to an m-class classification system in which sub-classes may be defined for each of the main aircraft and non-aircraft classes. The classification information is incorporated in the tracker's data association between tracks and measurements.

Classifier Enhanced Tracker Performance

	Existing Tracker	New Tracker	Percentage improvement
False tracks	164	7	96%
Clutter seduced tracks	8	0	100%
Broken tracks	27	14	48%
Clutter seduced and broken tracks	35	14	60%

- Statistics are collected for the Windfarm region
- A total of 50 targets go through the Windfarm region

Figure 7: Classification Aided Tracker with Windfarm Radar Data.

For the TRT technique, simulation was first used to generate a requirement, and then tested in the 3rd Generation HFSWR evaluation. Results here are from the simulation. Figure 8 shows that the RMSE in position and velocity obtained in the simulations for each algorithm. It is noted that the performance of the Retrodicted CMEKF is significantly better. In Figure 8, the retrodiction length L = 7 was used. The trend of the error reduction seems monotonically decreasing. With a retrodiction length L = 7, the errors in position and velocity are reduced by 30% and by 25%, respectively.

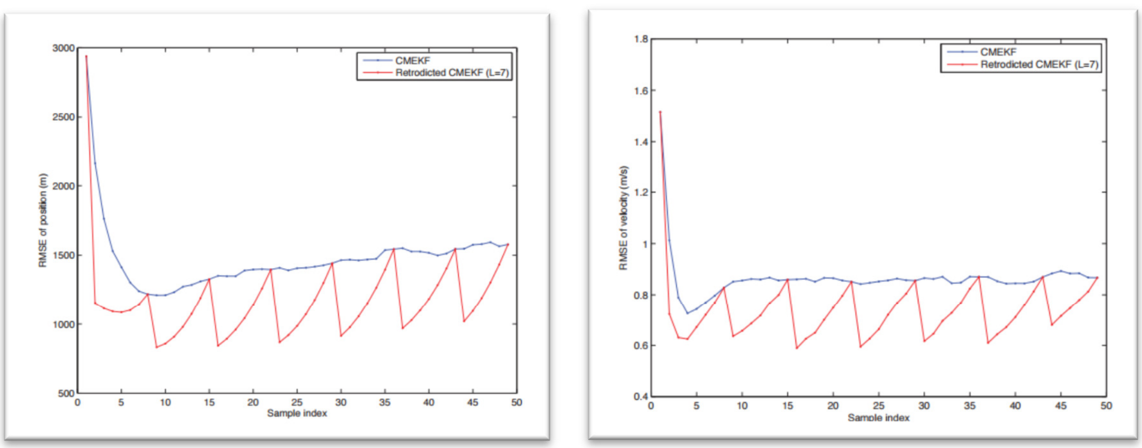

Figure 8: RMSE in Position and Velocity When L=7.

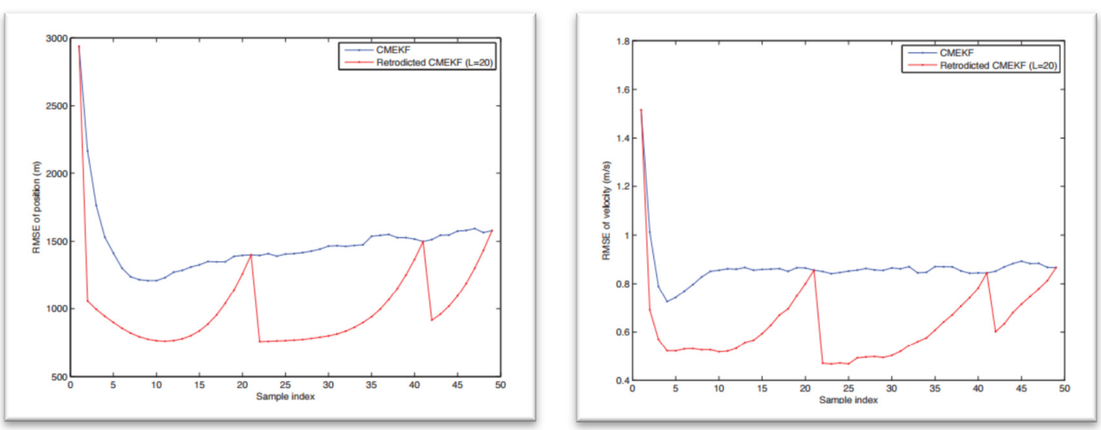

Figure 9: RMSE in Position and Velocity When L=20.

A longer window length L = 20 is also used for the same simulated data set, shown in Figure 9. It is noted that the performance of the Retrodicted CMEKF is significantly better again. Most importantly, the error reduction becomes flat, which means future data beyond 10 frames does not significantly reduce the current RSMSE in both position and velocity.

Conclusion

We presented a few intelligent feature aided techniques to handle radar tracking in dense clutter environments. Experiments and results are done with two radar applications, the HFSWR and the ATC radar. Four specific techniques, published and/or patented, are presented. These techniques are driven by tracking issues observed at various radar trials: Track Quality Tracker (TQT), Map Aided Processing (MAP), Classification Aided Processing (CAP) and Track Retrodiction Tracker (TRT). For each technique, either simulation and/or real radar data is used to evaluate the tracking performance. Upon significant performance enhancements, these techniques have been implemented in commercial radar products at Raytheon Canada Ltd. (RCL).

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