An Intelligent Agent based Track-Before-Detect System Applied to a Range and Velocity Ambiguous Radar.

E. J. Hughes, M. Lewis
Cranfield University, RMCS
Shrivenham, Swindon, SN6 8LA
ejhughes@iee.org, m.lewis@computer.org

Abstract

The problems associated with detecting low observable targets using Track-before-Detect systems based on Hough transform or Dynamic Programming techniques are reviewed. An alternative self-adaptive spatio-temporal CFAR system and a multiple hypothesis tracker based on Multiple Intelligent Software Agents and its adaptation to range and velocity ambiguous radar is described.

Introduction

In commonly used methods of track formation, target returns that cross a detection threshold are taken as 'potential targets'. A table of confirmed and potential tracks is used to classify the target returns into valid detections for existing tracks, possible targets worth investigating or noise.

With low observable and low flying targets (where multi-path can cause significant fading), many returns will be below the detection threshold and there may be many missing detections along the track, resulting in targets being classified as noise if re-investigated, tracks never being initiated, tracks being deleted early or each track being maintained for an extended period. In order to increase the probability of detection of weak targets, the detection threshold must be lowered with a consequent increase in the number of false alarms. As the information from the received signal is limited, a false alarm must be treated as a true target, until it can be established as false. The increased false alarm rate causes problems with the association of returns with tracks and leads to an excessive number of false tracks being reported with the consequent risk of the tracking system becoming overwhelmed.

Medium PRF radar systems allow all-round measurements of both the range and Doppler of targets in high clutter environments to be made. Such radars use waveforms that are ambiguous in range, Doppler or both. Existing techniques that resolve these ambiguities require the number of detections input to the ambiguity resolution process to be kept to a small number, as otherwise the number of false correlations ('ghosts') becomes unworkably large.

Another significant issue which affects many look-down airborne radars is the difficulty in distinguishing between unwanted ground moving targets and targets of interest with low closing rates. Commonly these unwanted targets are readily detectable, but must be excluded (for example, by Doppler filtering) to keep the ambiguity resolution problem within bounds.

The hypothesis of this research is that a pre-track system that exploits spatio-temporal Doppler correlations can be used to help reduce ghost targets, as well as reducing false alarms due to noise.

Track-Before-Detect Techniques

Track before detect or 'pre-track' operation has been proposed where either no threshold is applied, or a second low detection threshold is placed below the existing detection threshold to catch returns that did not quite cross the main threshold. These small amplitude detections are processed to see if they form tracks. The two main processing methods proposed are Dynamic Programming [1] and Hough Transforms [2]. Dynamic Programming is an optimisation process that tries to identify the single most likely track through each cell. A Hough Transform treats the data from a number of scans as an image and the method looks for 'lines' within the data. Both methods are computationally intensive with time complexity $O(N^3)$, additionally the Hough transform requires an extra step to re-associate returns with the set of possible tracks extracted from the transform. Fast approximate forms of the Radon, and the related Hough transform, also exist and have time complexity $O(N^2 \log N)$ [3]

Multiple Intelligent Software Agents

An intelligent agent is a form of software object that has the ability to store data internally, the agent's state, and a set of methods, both public and private, that modify the agent's state dependent on the current input environment and the agent's current internal state. The software agent usually has the ability to affect its environment, thereby influencing its own future behaviour and the behaviour of other agents. The agents often have the ability to communicate directly with other agents in a system, enabling complex self-organising behaviour patterns to emerge. The use of cooperating agents leads to a highly parallel structure formed from simple elements. This allows the system to be flexible, expandable, robust and fast to process.

The Track-Before-Detect problem has been investigated using multiple intelligent software agents, with the aim of producing novel alternative algorithms and has resulted in a Pre-Tracking system, rather than a Track-Before-Detect system that identifies tracks before applying thresholds. In the Pre-Tracking system, two thresholds are applied to the radar returns. The upper threshold is used to supply CFAR detections to the existing target tracking system (thus ensuring a level of performance no worse than conventional systems). The data crossing the lower threshold is used by the pre-tracker which is designed to tolerate a high level of false alarms.

The New MISA System

The key concept of the pre-track system is the exploitation of the spatio-temporal coherence of true target tracks, but with practical levels of processing. To achieve this, a self-adaptive spatio-temporal CFAR system is first used to identify 'interesting' radar returns. These 'interesting' returns are then passed to a pre-track system that attempts to associate the returns with previous returns according to a set of simple rules that define the likely feasible region that previous returns could lie in. The pre-track system does not make any explicit track predictions, unlike conventional multiple hypothesis trackers, but relies on associations between returns producing 'virtual' tracks within the data.

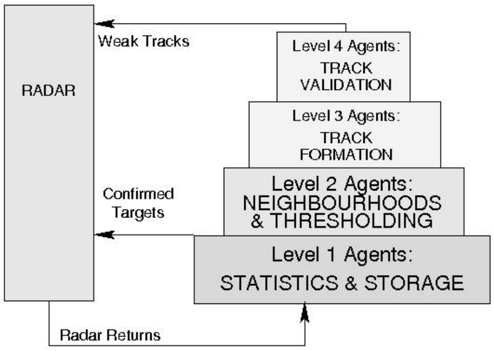

Figure 1 Functional Arrangement of MISA System

A system based on a hierarchical population of agents, each agent representing an individual radar cell that is allowed to self-organise into target tracks has been constructed. Figure 1 shows a functional block diagram of the current MISA system. The radar system is shown on the left, feeding the radar returns into the lowest levels of the agent hierarchy. The radar returns at this point will have had all necessary processing applied prior to the application of a CFAR system and a threshold.

Level 1 and 2 agents form a Spatio-Temporal CFAR Subsystem whilst Levels 3 and 4 function as a multiple hypothesis track forming sub-system. The radar returns traverse the hierarchy, with high-confidence target detections being fed to the main radar tracker as track segments.

The Behaviour of Typical Clutter Characteristics

Traditional radar detection systems make a binary decision, based on a threshold derived from the clutter level in adjacent range cells, as to whether the return is from a target, or noise/clutter. The decision mechanism directly affects the probability of target detection and the probability of a false alarm. The discrimination of false alarms is ultimately performed in the tracking system, and therefore the capabilities of the tracker will determine the maximum false alarm rate that can be tolerated, and therefore the minimum value for the decision threshold.

In practice, real clutter and noise are spatially non-homogeneous, requiring the threshold to be adjusted to maintain a maximum probability of detection, whilst not exceeding the maximum tolerable probability of false alarm. CFAR systems attempt to address this problem. The premise is that if the statistics of the noise/clutter are known, and a good estimate of the low-order moments (or central moments) is generated from the measured data, then a threshold level can be calculated that will achieve the maximum tolerable probability of false alarm. To estimate the low-order moments, samples are taken in range from around the return of interest.

The fundamental assumptions are that:

- the noise/clutter is locally homogeneous, allowing moments to be generated spatially;
- the statistics of the noise/clutter are stationary allowing accurate moments to be generated temporally;
- the shape of the noise/clutter probability density function is known;
- a low number of samples (typically 30) will provide a sufficient estimate of the moments;

Unfortunately these assumptions do not hold, except for a limited range of scenarios. One scenario where none of the assumptions are likely to be valid is the littoral environment.

It has been found that to gather sufficient samples to obtain a reasonable estimate of the mean and standard deviation, the samples must be drawn from a spatio-temporal-Doppler region. In order to make the samples as homogeneous as possible, the region must be optimised to the current environment and since this is unknown and dynamic, the region must be adaptive. As the statistics are non-stationary, only a limited time history may be used. Although sources of thermal noise are likely to be independent, clutter samples tend to be highly correlated. Thus the number of truly independent samples is reduced, again leading to poor estimates of the statistics.

The invalidity of the above assumptions directly influenced the structure of the Level 1 & 2 agent system.

The Spatio-Temporal CFAR Subsystem, Agent Levels 1 and 2

The basic functions of the Level 1 agents are to store a localised temporal history of the radar returns for their Level 1 range, azimuth and Doppler cell, generate statistics of the stored data, and apply the two thresholds to classify a return as noise, a partial detection, or a full detection. The Level 1 agents of the hierarchy record the time and amplitude information of each return together with its detection classification, based on the two thresholds. Level 1 agents are organised into small clusters of similar cells having their own Level 2 agent as shown in
Figure **2**. All detections that cross the upper threshold are passed to the radar for processing as likely targets using the existing track algorithms. This guarantees that performance is no worse than conventional CFAR.

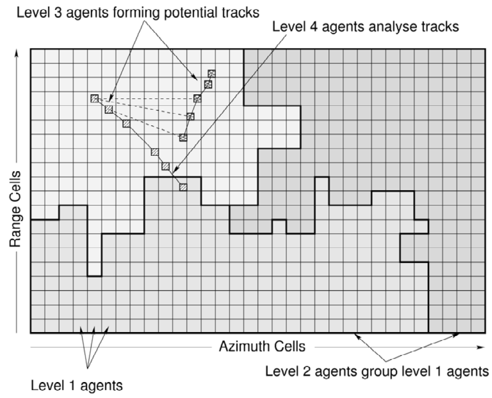

Figure 2. Cell-Level diagram of agent organisation (for 1 layer of Doppler cells)

Level 2 Agents

Level 2 Agents are virtual agents formed by Level 1 agents communicating with near neighbours and linking to form clusters that have similar probability distributions, e.g., in a littoral environment, land clutter is likely to have a Rician like distribution, whilst sea clutter will more likely follow a log-normal, Weibull or *K*-distribution. The exact choice to determine 'similarity' is very dependent on how the threshold level is calculated.
The Level 2 agents adapt by exchanging Level 1 cells with other neighbouring Level 2 agents, as shown in
Figure **2**, in an attempt to form a cluster. Unlike the Level 1 agents the Level 2 agents do not have fixed spatial locations.

A small housekeeping structure is associated with each Level 2 agent. This monitors the statistics on the quantity and distribution of the detections and partial detections from the Level 1 agents it is responsible for, and also the statistics of Level 1 agents in the local vicinity (controlled by other Level 2 agents). These statistics, along with feedback from the main tracking system in the radar, are used to generate the upper threshold. Feedback from the Level 3 agents is used in conjunction with the statistics to set the lower threshold. These threshold levels for the Level 1 agents within the cluster are used for the classification of the radar returns. The distribution will affect the calculation of the positions of these thresholds relative to the mean, median and standard deviation etc., calculated by each of the Level 1 agents.

The Level 2 system creates dynamically re-configurable spatial awareness within the processing system, allowing better statistical estimates to be generated for the calculation of the threshold levels. This grouping allows spatial correlations of the underlying clutter to be exploited, as well as the temporal correlations held in the Level 1 agents.

Range and Velocity Ambiguity Resolution

The output of the Level 2 agents is, in effect, a target/clutter map in range, azimuth and Doppler. In the case of MPRF radar the targets within the map are ambiguous in range and Doppler. The ambiguities may be resolved by operating on N PRFs, typically eight, and requiring target data in a minimum number, M, typically three, in what is generally known as an M of N (3 of 8) scheme [4]. Individual Level 1 and 2 systems are used for each PRF. A single target will appear at a distinct but ambiguous range in M of N Level 1 and 2 maps. The MISA technique exploits spatio-temporal correlation between returns to extend the ambiguity resolution process of a traditional M of N detection scheme such as the Coincidence Algorithm. This efficient coupling of ambiguity resolution with target tracking function provides an enhanced capability to distinguish true from false targets, and allows a higher false alarm rate to be tolerated with the generation of fewer ghost targets.

Potential Track Formation, Level 3 Agents

Conceptually, as shown in Figure **2**, Level 3 agents are formed with each being associated with a target return. When a Level 3 agent is created, it strives to form links with existing Level 3 agents that represent *virtual* tracks within the multi-agent system.

Using the 'Agent is a detection' approach allows many track hypotheses to be formed for each return. A similar approach has been used in systems based on Dynamic Programming [1], but no threshold was applied and every possible return was considered, which required massive amounts of processing. The Dynamic Programming approach has to rely on high resolution Doppler information in order to reduce the number of possible linkages that can be formed. In the MISA approach, only coarse Doppler information is available (if any) and potentially very slow to stationary targets may also be considered. It is assumed that given the limited information available, many tracks could pass through each Level 3 Agent.

Agents that are marked as having the potential to be part of a track are then scanned to see if any previous links are recorded. If links exist they are checked to determine if the speed and direction changes are within the feasible region. The calculation of the feasible region for association of agents to allow links to be formed whilst keeping processing to an absolute minimum is one of the cornerstones of this research. Explicit forward prediction of likely positions is not used as the basis of the association error, only reverse checks on link and agent feasibility are performed.

If the new agent is within the feasible region, the importance of the link is calculated. This Value can be used to prune the link set of the agent to reduce storage requirements.

Track Validation, Level 4 Agents

The primary function of a Level 4 agent is to assess the most likely path through a series of Level 3 agents and report the track to the main track database if it appears to be a true target. Level 4 agents are created when potential tracks are identified as a sequence of links formed between Level 3 agents. The Level 4 agent scans the track, looking for all the necessary correlations between stages that indicate a valid track is likely and eliminates unlikely tracks in the process. The Level 4 agent may also interrogate and analyse the target returns along the track in order to aid the track assessment by identifying possible missed detections. The Level 1 agent system is interrogated to see if a 'near miss' occurred when the data was thresholded. If a return is classified as belonging to a valid track at any time the Level 1 return may be promoted, the detection classification held in the temporal record being updated and the statistics describing the clutter updated accordingly. This process allows crisp tracks to be confirmed, some noise to be rejected, and areas of uncertainty to be identified.

As the number of agents reaches the upper limit of the processing capability, the life of the agents can be managed to allow a maximum population size to be maintained, whilst performance is allowed to degrade gracefully. This contrasts with conventional track formation where track overload can be catastrophic.

Once a track has been validated the track's elements are passed to the main radar tracker and the corresponding Level 3 agents notified that the track has been validated.

Project Status

At the time of writing a detailed prototype of the tracking system has been built and demonstrated on simulated non-coherent data from a marine navigation radar. The prototype has been extended to full Doppler processing capability and range and Doppler ambiguity has been added.

Results to date have demonstrated that for many target scenarios the ghost targets generated during the ambiguity resolution process are not correlated in a spatial-temporal-Doppler sense and are rejected easily by the MISA system.

There are also indications, however, that some target types (e.g., radial targets in close formation) may lead to ghosts that appear to be correlated in space, time and Doppler for a significant period.

The Levels of processing required to implement the Level 1 & 2 systems has been investigated and the capabilities of the full self-adaptive spatio-temporal CFAR system demonstrated. Multi-agent code has been written which has allowed the full dynamic threshold control system to be integrated with the Level 3 process and tested. The results, when compared against conventional methods including Cell Averaging CFAR, indicate that the multi-level system has the potential to provide a very significant pre-track capability.

Further Potential Applications

The ability to classify areas of returns is seen as having potential ECCM applications. The technique could be extended to IR and EO systems. It also has the potential for processing images in particle physics and astronomy.

Conclusion

Many existing CFAR approaches will produce very good results if the clutter statistics are known exactly, but can perform badly if there is even a small error in the estimated parameters. The result is that current CFAR techniques, by attempting to provide an optimal solution, can create a very fragile process.

In contrast the MISA process is, in effect, a simplified multiple hypothesis tracker, tightly coupled to a self-adaptive, context sensitive, spatio-temporal CFAR system. In environments with diverse clutter characteristics, the self-adaptive nature of the agent system self-organises using simple processing and by assuming that there will be too few data measurements to establish the clutter statistics accurately, a robust sub-optimal solution is formed. .

Acknowledgements

The prototype MISA pre-track system was developed as part of CRP programme contract no. RCSC/2/040. The extension to MPRF radar was conducted under contract to the EM & RS DTC.

In addition we wish to thank Dr., Sam Lycett, Qinetiq, Malvern and Dr., Andy Stove, Thales, Crawley for supplying radar return data that enabled the prototype MISA pre-track system to be evaluated

References

1. Arnold, J. Shaw, S. and Pasternack, H. 1993, *Efficient target tracking using dynamic programming*, IEEE Trans AES. Vol 29(1), 44--56

2. Storkey, A. J. Hambly, N. C. Williams, C. K. I. Mann, R. G, 2004, *Cleaning Sky Survey Databases using Hough Transform and Renewal String Approaches,* Monthly Notes of the Royal Astronomical Society Vol 347(1) 36—51

3. Brady, M. L. 1998, *A Fast Discrete Approximation Algorithm for the Radon Transform*, SIAM Jnl. on Computing, V27(1) 107—119

4. Alabaster, C. M. Hughes, E. J. 2003, *Medium PRF Radar PRF Selection Using Evolutionary Algorithms,* IEEE Radar Conference 2003, Huntsville, Alabama.