Novel algorithm for elimination of ghosts in ambiguous MTI radar

J R Hayes, IP Finley

QinetiQ Malvern & University College London

Abstract - In this study we have investigated a new method to reduce the number of ghosts produced by a medium pulse repetition frequency (PRF) MTI radar incorporating ambiguity resolution techniques. The paper introduces the concepts behind ambiguity resolution and ghost reduction techniques. Simulations have been carried out to verify the performance of the developed ghost reduction algorithm and the results are presented in this paper. It is shown that the ghost reduction algorithm is extremely effective at reducing the number of ghosts introduced by the ambiguity resolution algorithm.

1. Introduction

Medium pulse repetition frequency (MPRF) GMTI radars produce ambiguous range and velocity measurements. Techniques have been developed that can successfully resolve the ambiguous range and velocity measurements. However, when multiple targets are present the ambiguity resolution techniques not only produce detections at the correct target range and velocities, but also a number of additional false detections at incorrect ranges and velocities known as ghosts. In the absence of further information, it is not possible to determine which resolved detections are ghosts and which are targets. In effect, this is an additional mechanism that adds false alarms to the detections. In dense target environments the decoding of ghosts will reduce the interpretability of GMTI detection data and greatly diminish the military utility of the surveillance data.

The following sections report a study to investigate a new method of reducing the number of ghosts using target fingerprints. Fingerprints are measurable target attributes that are stable or similar over the duration of the waveform used to resolve the ambiguities. In this study the target attributes considered were the target range profile and the monopulse angle estimate.

2. Ambiguities

A pulse-Doppler radar detects targets by transmitting a pulse of radio frequency energy and receiving the energy reflected back towards the radar by a target. The target range can be deduced from the time between the transmission and reception of the pulse. Range ambiguities occur if the time between the transmission of the pulses, known as the pulse repetition interval (PRI), is smaller than the time taken for a reflection from a target of interest to reach the radar. The maximum range that can be detected within the same PRI as the transmission it originated from is termed the ambiguous range

A moving target will induce a Doppler frequency shift in the transmitted waveform. The velocity of a target can be deduced from the Doppler frequency shift. The two-way path between the radar platform and a moving target will change between pulse transmissions. This will result in a phase difference between successive pulse reflections. The phase change between successive pulses can be used to calculate the Doppler frequency shift produced by the target’s motion. Velocity ambiguities occur if the phase change between pulses becomes grater than a complete waveform cycle. The maximum velocity that can be detected before it is ambiguous is termed the ambiguous velocity.

If ranges greater than the ambiguous range are likely all range measurements become ambiguous, and if velocities greater than the ambiguous velocity are likely all velocity measurements become ambiguous

3. Resolving Ambiguities

Range ambiguities can be resolved by using multiple PRFs. Each PRF will result in a different ambiguous range. When a target range exceeds the ambiguous range of each PRF, the range measured by the radar will be different for each PRF. The true range can be deduced by calculating all possible values of range using Equation 1:

$$R = R_{rx} + mR_{\text{ambiguous}} \quad \text{(Equation 1)}$$

where R is the true target range, R_{rx} is the range measured by the radar, m is an integer multiple that corresponds to the number of times the target range exceeds the ambiguous range of the radar and $R_{ambiguous}$ is the ambiguous range of the radar. The number of times the target range exceeds the ambiguous range of the radar, m, is unknown and must be determined in order to determine the true target range. All possible ranges can be calculated using Equation 1 with all possible values of m. Each PRF will produce a set of possible ranges that contains the true range. The true range is the range that exists in all PRFs.

The same principle is true for velocity ambiguities. Equation 2 can be used to calculate all the possible values of velocity:

$$V = V_{rx} + nV_{\text{ambiguous}} \quad \text{(Equation 2)}$$

where V is the true target velocity, V_{rx} is the velocity measured by the radar, n is an integer multiple that corresponds to the number of times the target velocity exceeds the ambiguous velocity of the radar and $V_{ambiguous}$ is the ambiguous velocity of the radar.

4. Ghosts

When multiple targets are present it becomes possible for incorrect associations, known as ghosts, to occur. The incorrect associations arise because it is not known which ambiguous detection in one PRF corresponds to an ambiguous detection in another PRF. All target combinations will be reported as a target detection. The radar system has no knowledge of the origins of each target, and therefore all target combinations are decoded. The number of ghosts will increase as the number of targets increase. The same mechanism for producing ghosts is applicable for both range and velocity. In dense target environments the decoding of ghosts will reduce the interpretability of GMTI detection data and greatly diminish the military utility of the surveillance data.A dense target environment is likely to produce a large number of ghosts. To maximise the military utility of GMTI data the number of ghosts must be kept to a minimum. A method for reducing the number of ghosts is needed. The aim of this study is to reduce the number of ghosts, with a novel ghost reduction algorithm, to maintain performance in target rich scenarios.

5. Fingerprinting

We propose a new method of reducing the number of ghosts by characterising each target detection with a set of measured attributes. A fingerprint is a measurable target attribute that is stable or quite similar over the duration of the waveform used to resolve the ambiguities. A true target detection that has passed the ambiguity resolution process will consist of a number of detections of the same target. A ghost will consist of a number of detections from different targets. A true target can become corrupted by detections from false alarms or falsely resolved detections. If each target detection is attributed a fingerprint these can be compared to determine whether the detections in each PRF are likely to have originated from the same target. The fingerprints used in this study to characterise the targets are the range profile and the monopulse angle estimate. The measured fingerprints will have statistical variability even though they originate from the same target. For this reason, it is possible to discard genuine targets if the threshold for similarity is too restrictive. This must be avoided as it is important that the probability of detection (PD) is not significantly affected by the ghost reduction algorithm.

6. Monopulse fingerprints

Monopulse processes the outputs from subdivisions (or subarrays) of the antenna to refine the angular position of a target within the radar beam. This is usually implemented in modern radars in order to improve the poor geolocation accuracy arising from the width of the radar beam. The monopulse angle measurement will vary between PRFs owing to varying signal strength and varying interference. The variation is often quoted in the literature as approximately one tenth of a beamwidth. Monopulse angle measurement will therefore change between measurements as determined by the signal to clutter plus noise ratio (SCNR). Nevertheless, monopulse measurements will tend to be similar between PRFs for the same target. It is therefore appropriate to consider monopulse angle as a fingerprint for ghost reduction. If the detections in each PRF are separated by an angle greater than the expected difference they are assumed to result from different targets and the resolved detection is declared a ghost.

The Chi-square test is used to evaluate monopulse angles measured for the detections that constitute a resolved target detection. Monopulse angles have a normal probability distribution about the correct target location. The Chi-square distribution is used to find the probability that a set of monopulse measurements originate from the same target. The Chi-square distribution is the density of the sum of the squares of n independent normal variables. A target association is kept if the probability is above an empirical threshold, which is chosen to maintain an acceptable PD.

A target detection may result from a number of correctly resolved and falsely resolved targets.
The falsely resolved targets will corrupt the monopulse measurements for the correctly resolved targets and cause the correctly resolved target to go undetected. In order that the correctly resolved targets pass the Chi-square test subsets of detections must be considered. The monopulse ghost reduction algorithm finds the largest subset of monopulse angles that pass the Chi-square test. The detections that correspond to the subset of monopulse angles are kept and the remainder discarded.

7. Range profile fingerprints

Range profiles can be used in a similar manner to monopulse angle estimates to reject ghosts. This requires that the radar has fine range resolution. For the purposes of target detection the range resolution is degraded (e.g. to typical vehicle size of 10-15m) to reduce the complexity and computation load. If the target aspect angle is unchanged between PRFs and the RF frequency is constant between PRFs, the target range profile will not change apart from the random background interference due to internal thermal noise. At constant RF, the larger the change in aspect angle between PRFs, the larger the change in the range profile. This could have a direct impact on the effectiveness of range profiles for fingerprint ghost reduction because the most important characteristic of a fingerprint is its similarity between PRFs.

The method of comparing range profiles is more complicated than that of monopulse angle estimates because the range profile is not a single measurement but a set of measurements in each range bin.
Autocorrelation is carried out on each range profile which has the effect of making the range profiles shift invariant. The range profiles are then compared on a pair-wise basis using a correlation function
From a set of range profile we must identify a subset of range profiles that are likely to have been measured from the same target. Graph theory has been adopted to identify the subsets of range profiles where each pair of range profiles in the subset are correlated above an empirical threshold.

8. Simulation Results

The ambiguity resolution process has been tested using simulated radar data of target detections and monopulse angles in conjunction with measured high resolution range profiles (HRRP). Simulated data have been chosen to model the detection scenario as it provides complete freedom in the choice of radar parameters, allowing any possible operating scenario to be realised. The choice of radar parameters can be chosen to reflect best the operating conditions of a typical long range surveillance GMTI radar. However, experimental HRRP data are required because accurate modelling of radar scattering in each high resolution range bin is difficult to achieve. HRRP experimental data have been obtained by placing different vehicles on a rotating turntable and measuring the range profile with an experimental radar on a tower.

A radar simulator has been written in MATLAB to model a GMTI radar with ambiguity resolution and ghost reduction. The simulation program has been used to simulate a GMTI radar operating with a MPRF. A PRF schedule of 5 PRFs and a PRF schedule of 8 PRFs have been simulated. An area of ground containing 1000 randomly placed targets has been modelled. The simulation and modelling are representative of a long-range surveillance radar. The results from the Monte-Carlo runs have been averaged and are presented in Table 1. The table shows the number of ghosts produced by the ambiguity resolution algorithm and the percentage of the ghosts that has been removed by the ghost reduction algorithm.

	5 PRFs		**8PRFs**	
Fingerprint Method	Number of Ghosts	Ghosts Remaining	Number of Ghosts	Ghosts Remaining
None	38.6	-	244	-
Monopulse	1.1	3%	10.8	4.4%
Range Profile	18.8	48.7%	123.7	50.7%
Combined	0.58	1.6%	6.0	2.4%

Table 1

9. Conclusions

The simulations have shown that range profiles ghost reduction is modest. However monopulse angle ghost reduction is very effective. By combining the two methods an increased performance is achieved. The monopulse ghost reduction algorithm is relatively simple and has a low computational load. Therefore, it is recommended that the algorithm is employed by any radar that has a monopulse angle function and uses multiple PRFs for ambiguity resolution. The small increase in performance gained by combining monopulse and range profile ghost reduction comes with a significant increase in computational load. It is therefore recommended that combined monopulse and range profile ghost reduction is only employed by operational radars if the extra processing expense can be accommodated. Incorporating ghost reduction algorithms into a GMTI radar system will significantly increase the quality of the GMTI data.