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Medium PRF Schedules for Airborne Fire Control Radar

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Introduction

Many modern radar systems use medium pulse repetition frequency (PRF) waveforms to measure target range and velocity in the presence of clutter. Medium PRF waveforms offer excellent clutter rejection characteristics which render them an attractive proposition for airborne fire control radar plus a variety of other military radar applications. This paper describes work to optimise the selection of precise values of PRF for a variety of medium PRF schedules and to rate the quality of the solutions found.

Medium PRF

A medium PRF is characterised as being range and velocity ambiguous. Unambiguous range and velocity may be decoded through a comparison of the ambiguous target data received in a minimum number, M, PRFs from a total number, N, transmitted in what is known as an *M of N* schedule. Each medium PRF is also characterised by having blind ranges associated with eclipsing losses and overwhelming side lobe clutter (SLC) and blind velocities associated with the rejection of main beam clutter (MBC) and its repetition in the frequency domain. This blindness requires $N > M$; 3 of 8 being commonplace.

The Optimisation Process

The optimisation process is based on an evolutionary algorithm and uses a model of an airborne fire control radar and associated clutter model to trial the quality of each potential solution. The process is depicted in Figure 1. The optimisation process is driven so as to reduce range/Doppler blindness and includes checks which guarantee that all schedules are decodable, avoid blind velocities, minimise the risk of ghosting and conform to limits dictating the maximum, minimum and mean PRFs allowable.

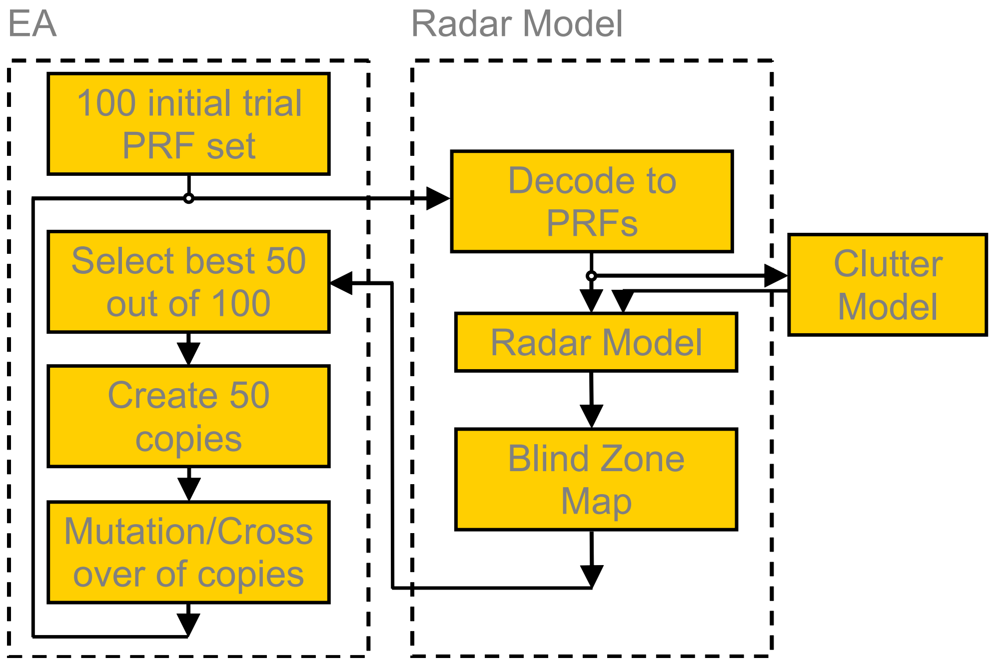

Figure 1: The Optimisation Process

The optimisation process is designed to identify optimum PRF schedules varying in length from 5 to 9 PRFs and requiring target data in three PRFs (as is the norm) and in just two PRFs.

The Radar Model

The details of the radar model are given in Table 1.

Parameters	**Value**
Carrier frequency	10 GHz
Max & Min PRI	150 to 35 μs
PRI resolution	10ns (11501 PRIs)
Transmitted pulse width	7 μs
Compressed pulse width	0.5 μs
Compression ratio	14 (linear FM Chirp)
FFT size	64 point
Range resolution	75 m
Blind range due to eclipsing	15 range cells
Duty cycle	Variable (0.2 peak)
Ambiguity resolution	Coincidence algorithm
Beamwidth	3.9^0
Scan rate	$60\ ^0/s$
Target illumination time	65 ms
MBC/GMT rejection bandwidth	± 1.67 kHz (25m/s)
Maximum target Doppler	± 100 kHz (1500m/s)
Maximum detection range	185.2 km (100 nmi)
Target radar cross-section	$5\ m^2$

Table 1: Radar Model Parameters

The fine PRI resolution (10ns) ensures that many closely spaced PRF values are available to the optimisation process and also ensures that *2 of N* decodable schedules may be found. The large number of PRFs available (11501) increases the complexity of the optimisation, and therefore demands the evolutionary approach, but results in superior solutions.

Target Extraction

This work assumes the use of the Coincidence Algorithm for decoding target range and Doppler, since it is less constraining on PRF choice than the Chinese Remainder Theorem. A target extraction algorithm has been developed which is designed to reject ghost targets and promote the declaration of true target range/velocity. The algorithm is based on the concept that genuine targets are characterised as being visible in a large number of PRFs in a small region of range/Doppler space, whereas ghost targets are more likely to be observed in a few PRFs. It also discounts any potential targets containing detection points already attributed to genuine targets. Therefore, potential ghost targets containing the detections of genuine targets which are repeated in the time and frequency domains are dismissed.

Tests were conducted on the following PRF schedules, which were identified as having the least blindness in each schedule type:

Best *2 of 6*	PRIs = 64.04, 74.53, 83.03, 92.07, 100.75, 118.80 μs
Best *2 of 7*	PRIs = 73.55, 81.03, 89.76, 99.42, 109.50, 116.46, 125.17 μs
Best *2 of 8*	PRIs = 78.92, 81.56, 86.66, 90.46, 99.81, 111.81, 117.09, 128.56 μs

Best *3 of 8* PRIs = 63.11, 69.97, 77.07, 81.31, 90.06, 99.90, 109.75, 119.00 μs

Two test matrices were derived which explored various combinations of variables for randomly distributed targets (random range and velocity) and close formation targets (150 metre separation, same velocity) plus the addition of false alarms. Five hundred experiments of each combination were ran in order to generate statistics on the correctly reported targets, additional targets (i.e. ghosts), genuine targets not reported and blind targets.

Results – Blindness

One hundred runs of the optimisation process were performed for each schedule (*M of N*) and used to generate the blindness statistics of Table 2. The data of Table 2 refer to the percentage of range/Doppler space which is visible in fewer than *M+1* PRFs and includes blindness due to overwhelming SLC and the first blind range and blind velocity, both of which are unavoidable.

M from N	Min %	Max %	Mean %	Median %	σ %
2 from 5	66.10	66.73	66.43	66.44	0.1434
3 from 8	58.37	59.91	59.01	59.02	0.2803
2 from 6	56.35	57.70	57.12	57.18	0.3316
3 from 9	53.74	55.02	54.46	54.51	0.2656
2 from 7	48.90	50.24	49.46	49.54	0.3437
2 from 8	44.13	45.21	44.59	44.57	0.2296

Table 2: Blindness Results

Results – Ghosting

In all cases, approximately 95% of genuine targets were correctly reported, irrespective of the schedule or number of false alarms. The 2 of 8 schedule was consistently, though marginally, the best. Additional ghost targets were between 0.5 to 1% of the genuine number of targets but generally higher (up to 4 – 6% depending on conditions) for the 2 of N schedules. Longer schedules resulted in fewer ghosts. Blind targets mirrored the blindness performance of each schedule and targets not reported (around 1%) followed the trends in incidence of ghosts.

Conclusions

The evolutionary algorithm has been successful in optimising the selection of PRF values of various medium PRF schedules for minimal range/Doppler blindness. The repeats runs of the optimisation indicate the existence of several similar local optima and the ability of the evolutionary algorithm to find them. Blindness is minimised in schedules requiring target data in fewer PRFs ($M = 2$) and for longer schedules ($N = 8$); the former being the most significant.

The numbers of ghost targets remained very low for the *3 of 8* schedules and were only slightly degraded in the *2 of N* schedules. The target extraction algorithm was most reliable for the longer schedules. Close formation targets gave rise to more ghosts than targets of random range and Doppler since close formations of identical Doppler only require correlation in range to register as ghosts. Unreported targets were very low in all schedules but tended to follow the trends in the reporting of ghosts. Correctly reported targets were maintained at a high level but were marginally superior for the *2 of 8* schedule. The highest incidence of ghosts (*2 of 6*, close formation targets) also corresponded to the lowest incidence of correctly reported targets, since ghosts were being declared in preference to correct targets. The numbers of blind targets followed the trend in blind zone performance.

In summary, each schedule type has areas of relative strength and weakness, however, the best and worst schedules do not differ appreciably from each other. This study has shown that *2 of N* schedules can be considered viable and even advantageous with respect to the more conventional *3 of N* schedules in many areas. In particular, the detection performance of an optimal *2 of 6* schedule is very similar to that of an optimal *3 of 8* schedule but enjoys the benefits of being a shorter schedule i.e. faster optimisation speed.