Analysis of pulse repetition frequencies for distributed radars in Adapt_MFR and v3.2.11 software release notes

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Contract Number: W7714-125424
Contract Scientific Authority: Dr. Peter Moo 613-998-2879

Contract Report
DRDC-RDDC-2016-C107
March 2016

Abstract

DRDC Ottawa has contracted C-CORE for software support services related to the analysis of pulse repetition frequencies (PRF) for distributed radars. Analysis and testing was performed using the Adaptive Multi-Function radar simulator (Adapt_MFR) with particular interest in using target localization to resolve range ambiguity at higher PRFs.

The main purpose of this work was to analyze PRF trade-offs for the resolution of range and Doppler ambiguities and to characterize target localization for distributed radars as well as analyze the effect of PRF on range and Doppler ambiguities for distributed radars.

Several Adapt_MFR simulations were performed using both single radars with different PRF values and multiple radars with a shared central tracker and coordinated radar resource management, which assigns tracks to specific radars. It was expected that the differing PRFs used in a multi-radar simulation would result in improved target detection and consequently track completeness due to greater target return power outside the unambiguous range and Doppler zones. However, no significant change in track completeness was observed. When performing track assignment to specific radars in coordinated RRM the tracker does not currently use knowledge of ambiguity zones and can assign tracks to the radar that has a PRF which positions the track in an ambiguity zone. This could result in a lost detection and lower track completeness.

Through analysis and testing it has been determined that the Adapt_MFR software in its current form cannot support/simulate target localization when using multiple radars and/or multiple bursts per radar and the centralized tracking structure due to the limited range and Doppler ambiguity modeling. The tracker could be restructured into a de-centralized form to implement some of the target localization methods investigated; however, it might be preferable to implement range and Doppler ambiguity into the pre-track software and have the centralized tracker or a new pre-tracker ambiguity resolver handle ambiguity resolution using target localization instead. The centralized tracker would however have to be modified to work with multiple independent radars rather than through the current coordinated management scheme. Some limited work was done to model a central tracker with multiple independent radars but several tracker modifications are still required.

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1 Introduction

DRDC Ottawa has contracted C-CORE for software support services related to the analysis of pulse repetition frequency (PRF) selection and the effect of that selection on range and Doppler ambiguity, in particular for a distributed radar situation (or a multi-radar simulation when using the Adaptive Multi-Function radar simulator (Adapt_MFR)). There is an interest in implementing target localization with multiple radars to resolve range ambiguity at higher PRFs. All analysis and testing was performed using Adapt_MFR version 3.2.11.

During analysis and testing, the software was updated with bug fixes and speed improvements to lower simulation run time. Some usability improvements were also made. This work builds upon the previous work described in Brinson (2015).

This report summarizes the work done under Task 7 of Contract W7714-125424 which includes the analysis of PRF, investigation into the target localization implementation, and the addition of bug fixes, execution speed improvements and usability improvements to the software.

2 PRF analysis

This section describes the PRF testing and analysis that was performed using Adapt_MFR. The simulation parameters used, the limitations encountered and some results are described in the following sections.

2.1 Simulation parameters

The 52 target scenario file scenario_no_birds_2014c (Figure 1) was used. All simulations using one radar were done so with independent radar resource management (RRM) and simulations using two radars were done with coordinated RRM, as described in Moo (2015). Table 1 shows some additional parameters used during simulations. Table 2 lists the PRF and pulse width (PW) values tested as well as the maximum unambiguous range (R_{unamb}), the blind range (R_{blind}) at each range ambiguity, the maximum unambiguous velocity (v_{unamb}), the minimum observed frame time (t_{frame}) and the simulation number (used to associate output files with parameter settings). In multi-radar simulations the antennas are all located at the same position and height otherwise, when using coordinated RRM, tracks would always be assigned to the radar at lower range. The goal of the multi-radar simulation in these cases is to have the targets tracked using many different PRFs. Adapt_MFR uses one central tracker structure for all radars. New logic in the software changes the track to radar assignment periodically as discussed in Section 5.7. Note that clutter and jamming are not included in the simulations discussed in this paper but will have an additional significant impact on PRFs chosen for ambiguity resolution.

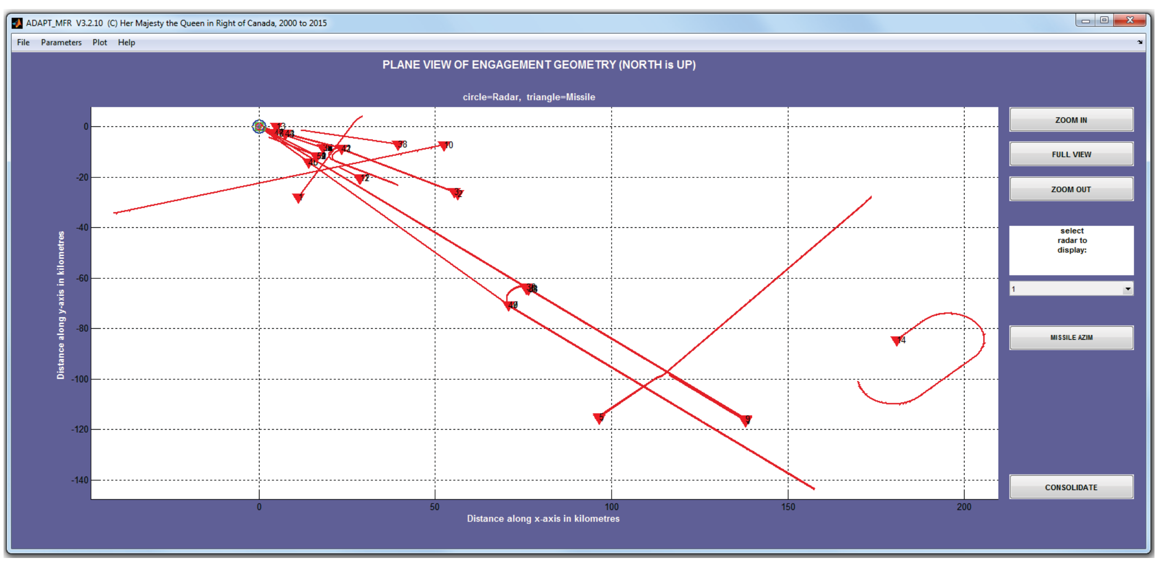


Figure 1: *Scenario plane view, 52 targets*

Table 1: *Select Adapt_MFR parameters used in Simulations*

Transmitter frequency:	3e9 Hz
Antenna boresight:	90 degrees (North is 0 degrees)
Azimuth scan limits:	-60 : 60 degrees w.r.t boresight
Azimuth beam spacing:	3 degrees
Elevation scan limits:	0 : 20 degrees w.r.t boresight
Elevation beam spacing:	2.3 degrees
Antenna diameter:	2.3 m (Az and el)
Number of antenna bursts:	1
Pulses per burst:	8
Pulse compression ratio:	512
Peak power:	10 kW
Track update rates:	Target priority ≥ 0.75: update rate = 1.5 s Target priority < 0.75: update rate = 3 s

Table 2: *PRF and PW values tested*

PRF, Hz	PW, s	max R_{unamb}, m	R_{blind}, m	max $v_{unamb}, m/s$	min t_{frame}, s	sim #
303	38.8E-05	494719	58202	15	10.4	20163181740
603	19.5E-05	248590	29246	30	5.1	20163181928
903	13.0E-05	166002	19530	45	3.3	2016318213
1303	9.03E-05	115042	13534	65	2.3	2016319034
6303	1.87E-05	23782	2798	315	0.47	20163191524
9303	1.26E-05	16113	1896	465	0.32	2016320047

2.2 Range and Doppler ambiguity blind zones

Adapt_MFR has a function *blind.m* that allows plotting of range and Doppler ambiguity blind zones based on PRF and PW values. For pulse-Doppler radar scalloping occurs at these range/Doppler ambiguity areas which reduces target return power and track sensitivity. Figure 2 shows the velocity versus range profile of all 52 targets tested. Figures 3 through 8 show the blind zone maps resulting from the PRF values tested with the same velocity versus range sizing and a zoom on the first velocity and range ambiguity. These blind zones correspond to the values shown in Table 2. By comparing the blind zone maps to the velocity versus range profile of the targets one can see where tracking might be affected by ambiguity for each PRF/PW pair tested. Pulse-Doppler radars usually compensate by using three or more different PRFs. This will be further discussed in Section 3 regarding target localization.

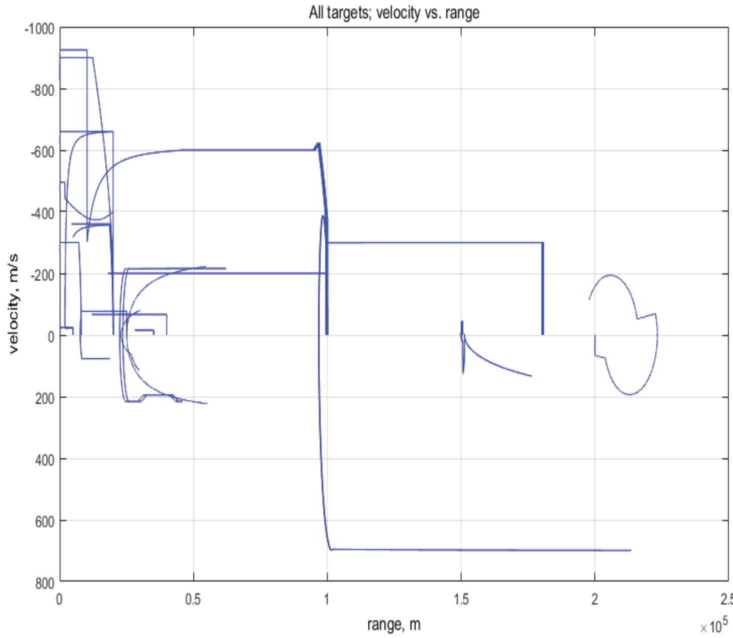
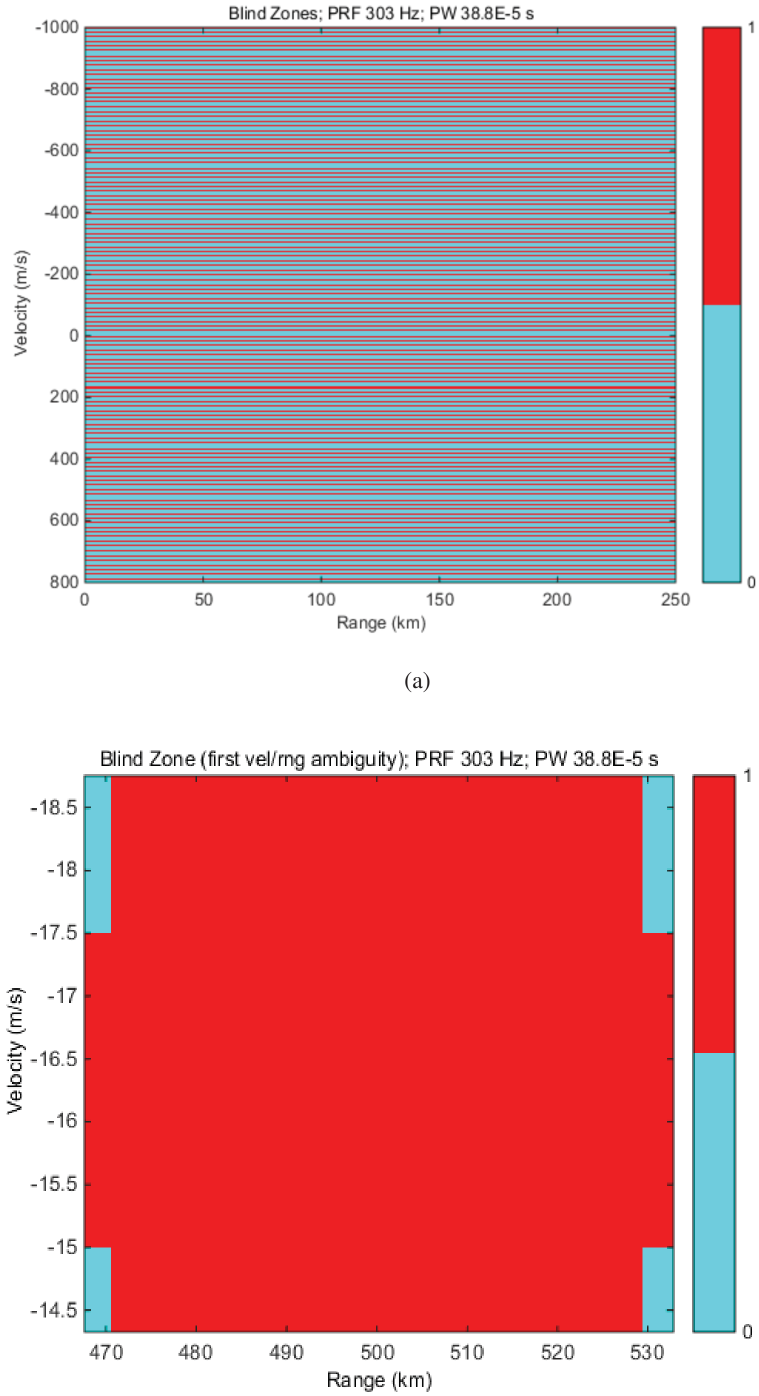


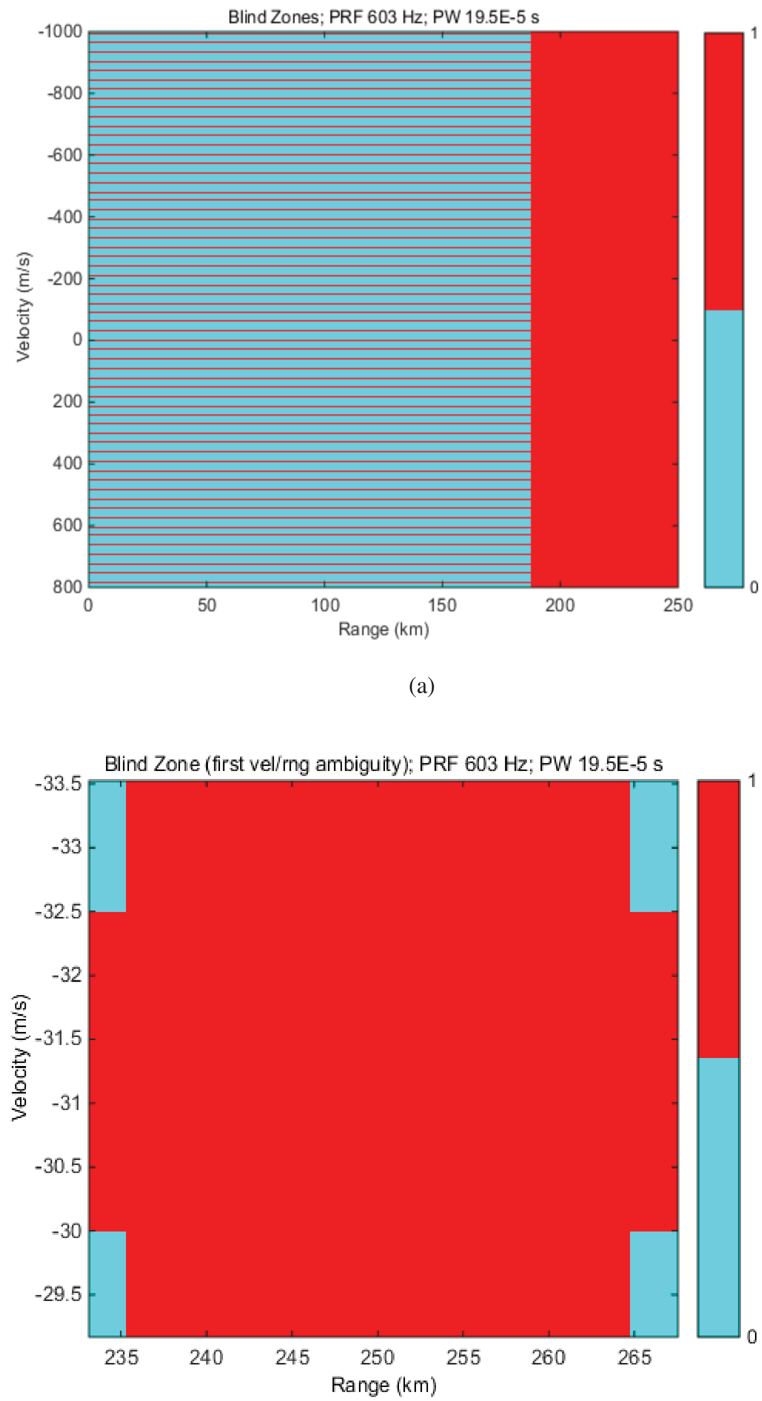
Figure 2: *Velocity vs range, 52 targets*



(a)

(b)

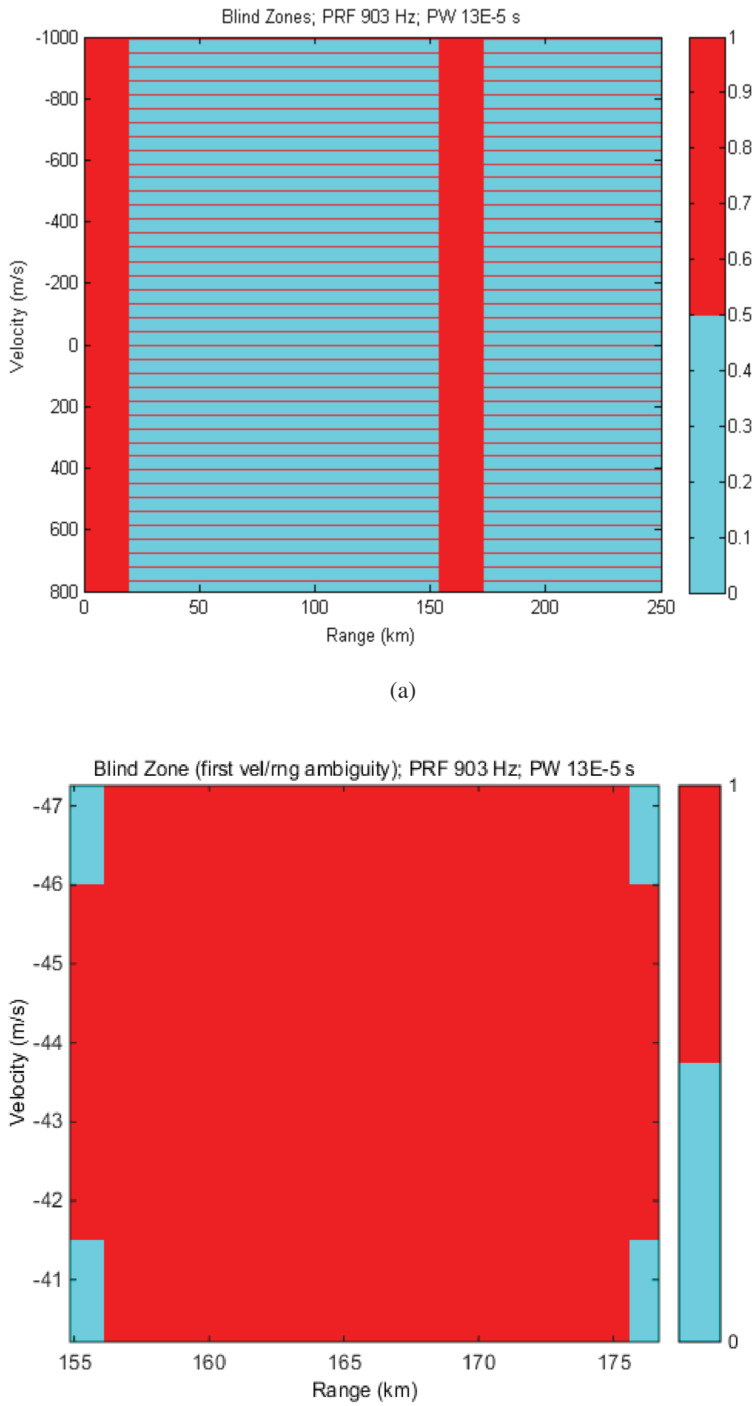
Figure 3: *Ambiguity map using PRF of 303 Hz. (b) Zoom on first velocity & range ambiguity*



(a)

(b)

Figure 4: *Ambiguity map using PRF of 603 Hz. (b) Zoom on first velocity & range ambiguity*



(a)

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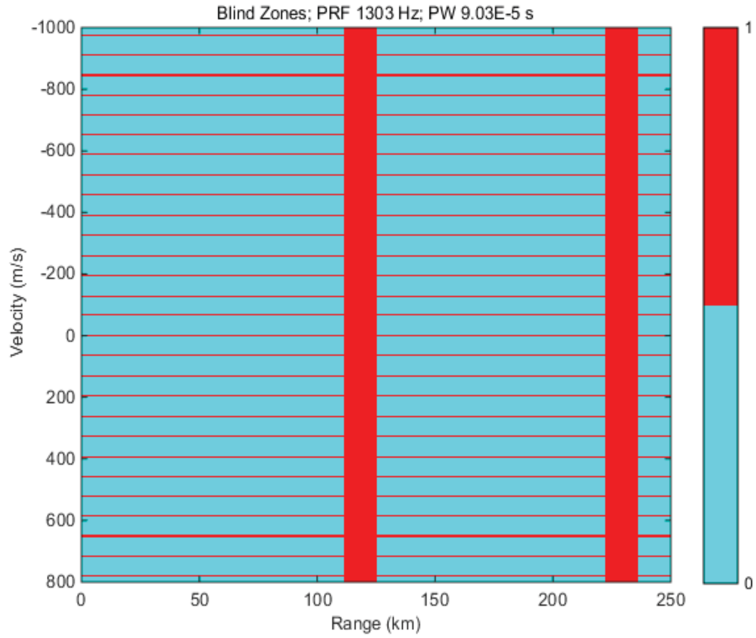
Figure 5: *Ambiguity map using PRF of 903 Hz. (b) Zoom on first velocity & range ambiguity*



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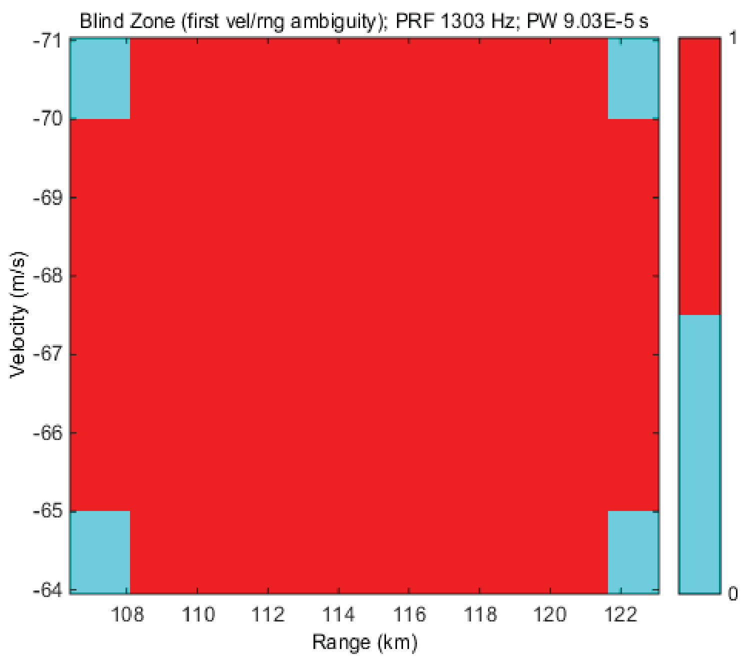
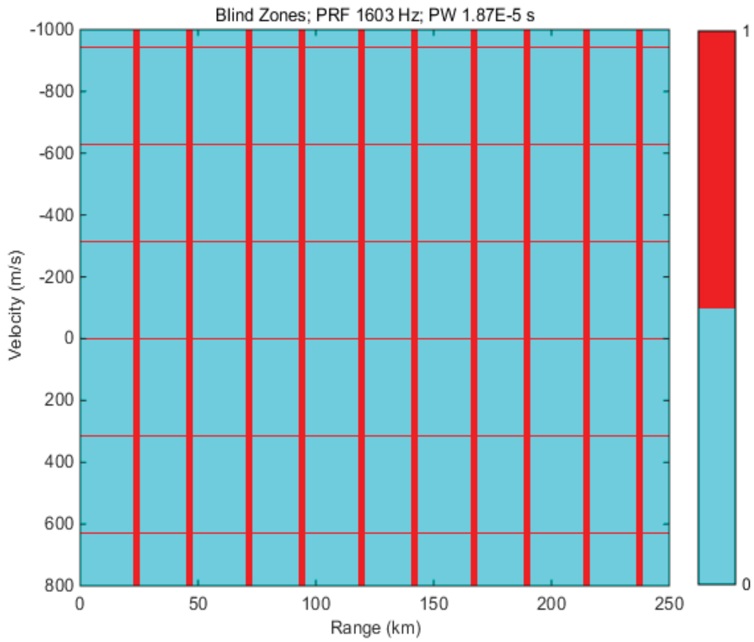
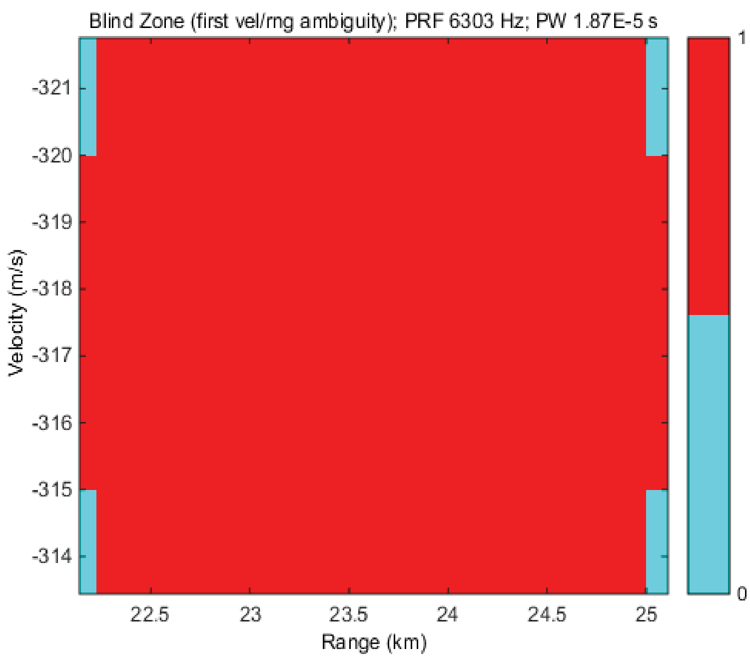


(b)

Figure 6: *Ambiguity map using PRF of 1303 Hz. (b) Zoom on first velocity & range ambiguity*

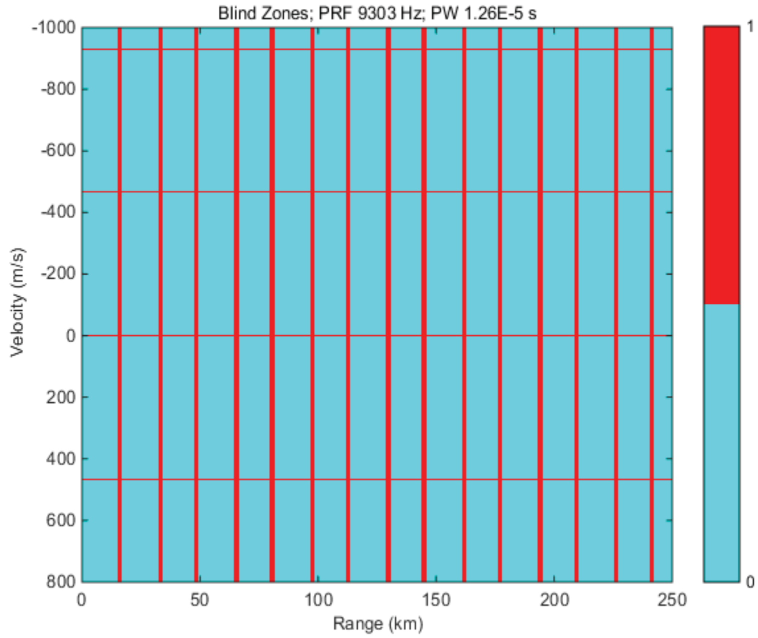


(a)



(b)

Figure 7: *Ambiguity map using PRF of 6303 Hz. (b) Zoom on first velocity & range ambiguity*



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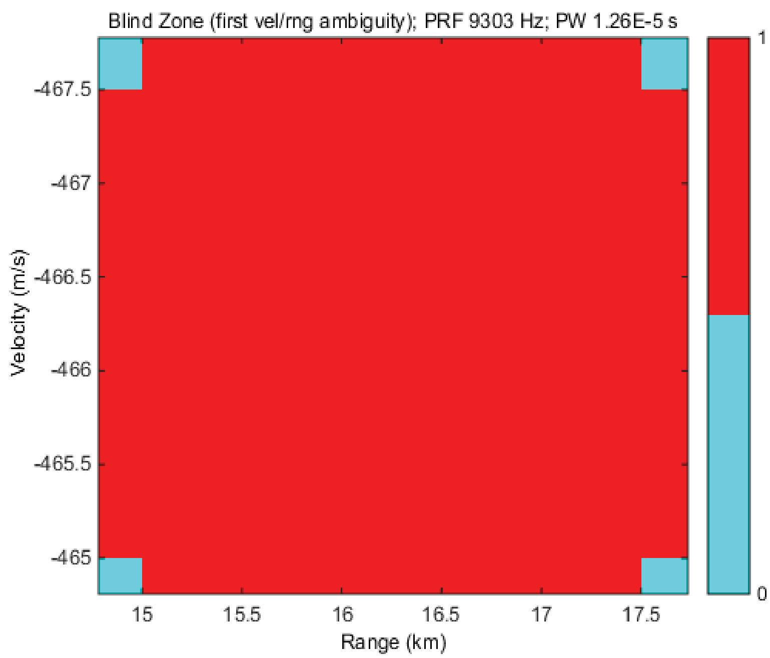


(b)

Figure 8: *Ambiguity map using PRF of 9303 Hz. (b) Zoom on first velocity & range ambiguity*

2.3 Problems encountered

A number of problems were encountered during testing and analysis which slowed progress and required parameter changes and simulation re-runs.

A software bug was encountered that allowed improper combinations of PW and PRF. Simulations ran without error or warnings but the results were flawed. Continually increasing the value of PRF while keeping PW the same kept improving track completeness. A bug fix was applied which is described in Section 5.1.

When testing combinations of different PRF values with multi-radar scenarios a radar indexing bug was discovered that resulted in track elevation values being used incorrectly for the wrong target tracks. The bug fix is described in Section 5.4.

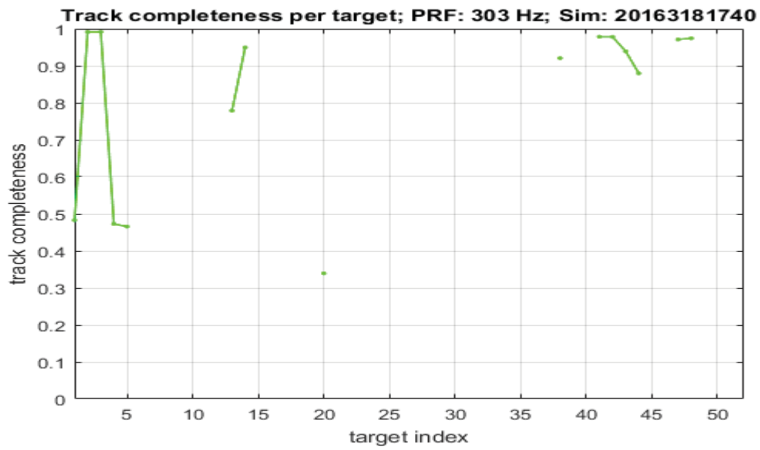
Additionally, for the initial multi-radar scenarios, a radar assignment logic problem occurred which resulted in tracks always being assigned to the first radar. This resulted in a tracking problem when the first radar had a low PRF in comparison to the other radar(s). A software modification was made and is described in Section 5.7.

2.4 Limitations of Adapt_MFR related to range and Doppler ambiguity

The Adapt_MFR simulator is limited in that there are no range or Doppler ambiguities applied to detections sent to the tracker. The range and velocity input values read in from the target input file are basically sent directly to the tracker when the target return meets the detection requirements. These requirements are in terms of gain and signal-to-noise ratio (SNR) and are influenced by antenna parameters and target radar cross section (RCS), as well as other factors. Range ambiguity and eclipsing is calculated by the *eclipse(...)* function which is called by the *compute_radarRangeEquation(...)* function and results in a reduction in target return power at range ambiguities. The target power is passed into the *Doppler_mfr* function which calculates several SNR and signal-to-interference (SIR) results. Targets falling in or near ambiguity regions may not be detected well (or at all) at certain times during the simulation potentially resulting in a reduction in track completeness. So the effect of ambiguity is applied to target return power however the original unambiguous range and velocity values are still sent to the tracker. This will be further discussed in Section 3.2.

2.5 Results

Figures 9 through 14 show the track completeness, track occupancy and frame time results for the PRF/PW combinations tested.



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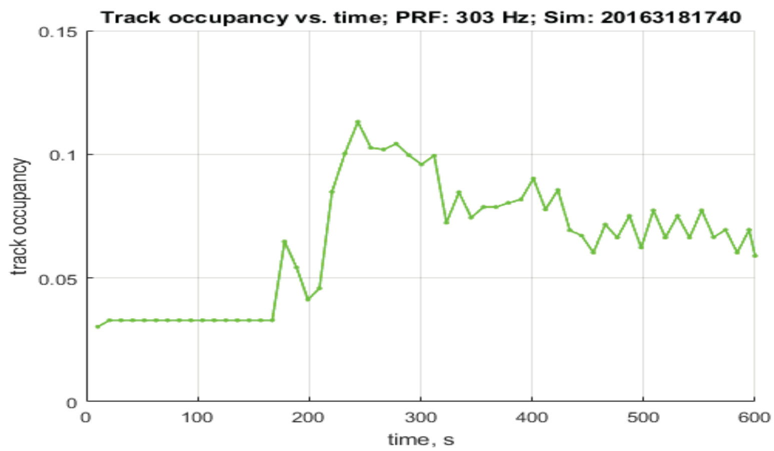

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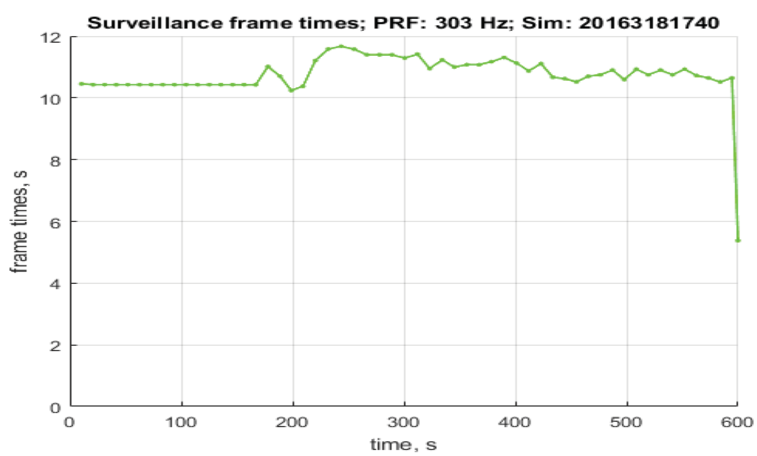
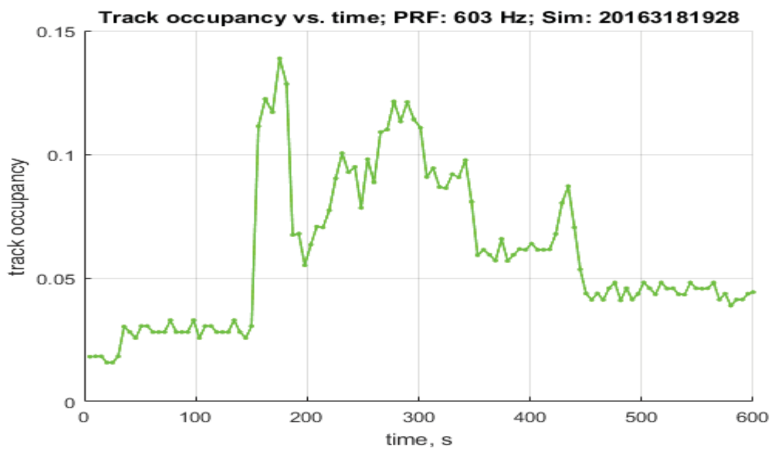


(c)

Figure 9: *Results using PRF of 303 Hz. (a) Track completeness. (b) Track occupancy. (c) Frame time.*

(a)



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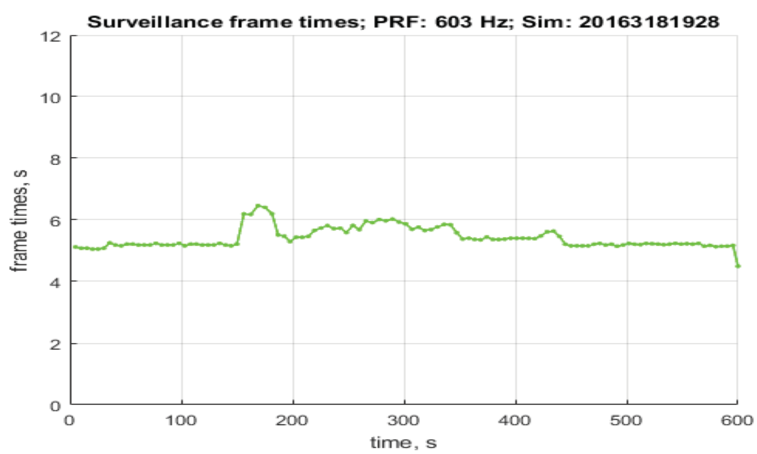
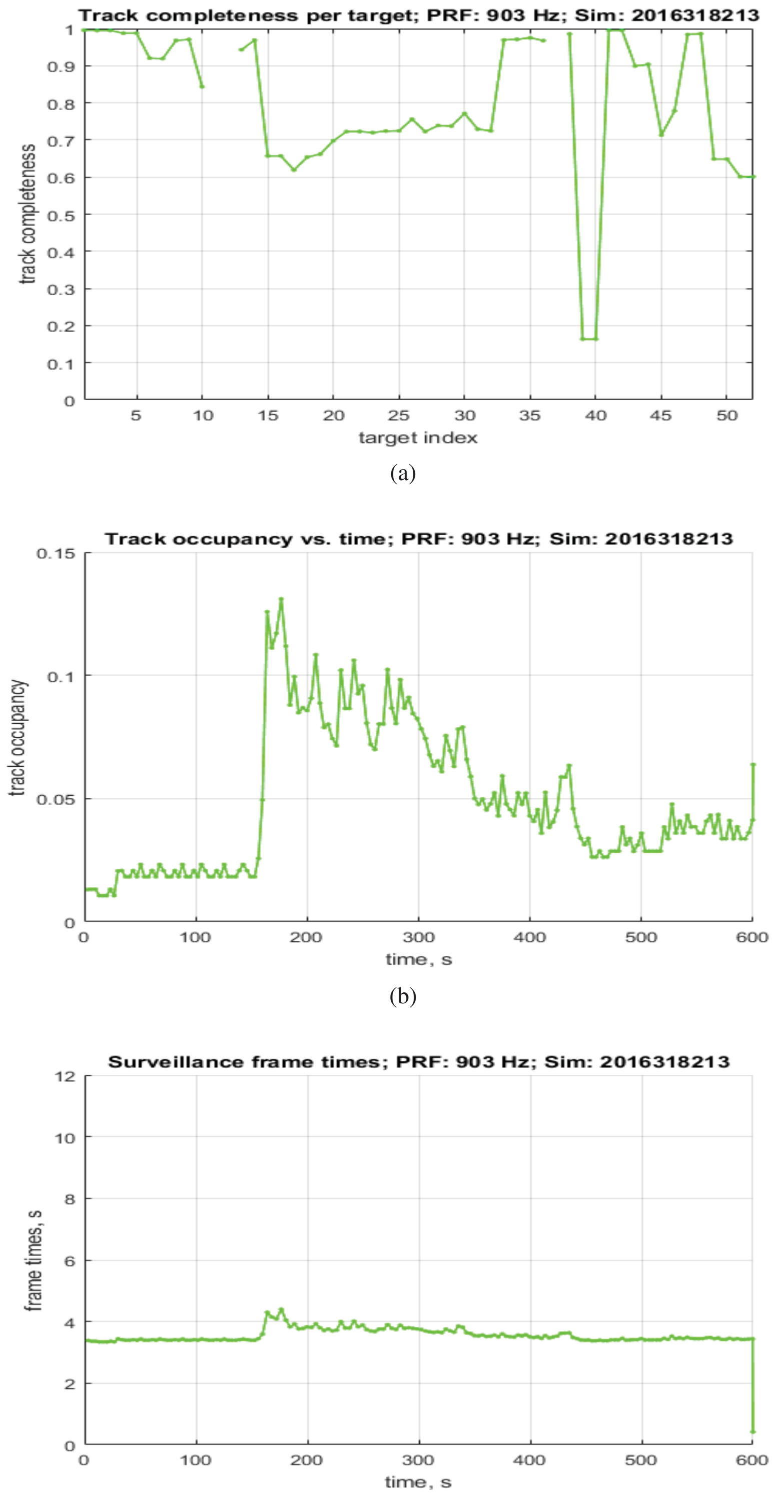


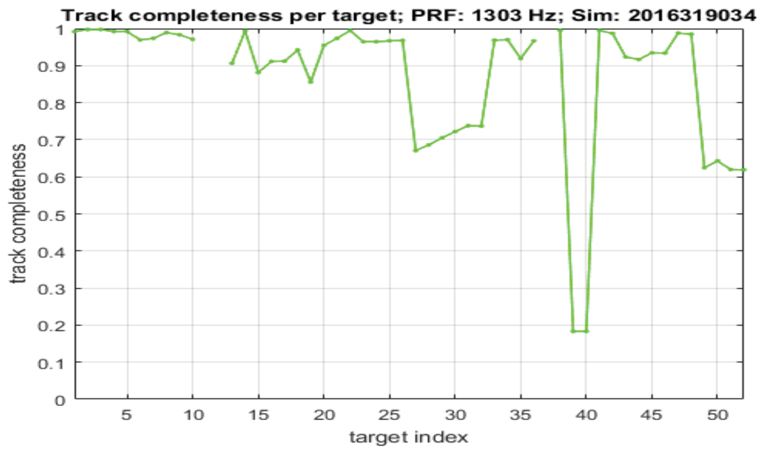
(c)

Figure 10: *Results using PRF of 603 Hz. (a) Track completeness. (b) Track occupancy. (c) Frame time.*

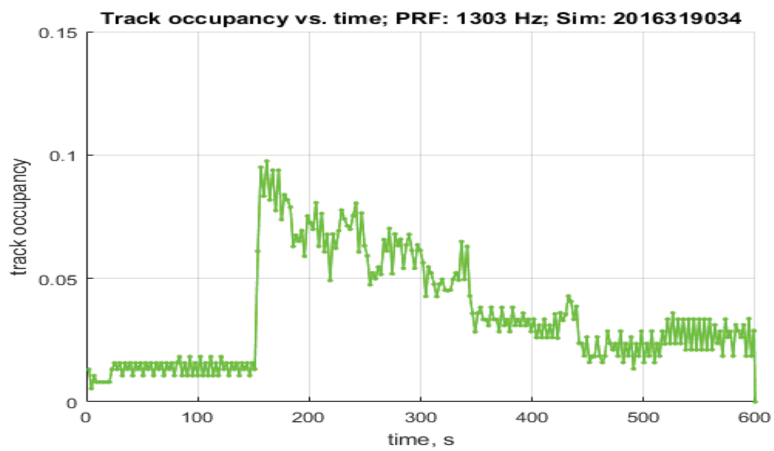


(a) (b) (c)

Figure 11: *Results using PRF of 903 Hz. (a) Track completeness. (b) Track occupancy. (c) Frame time.*



(a)



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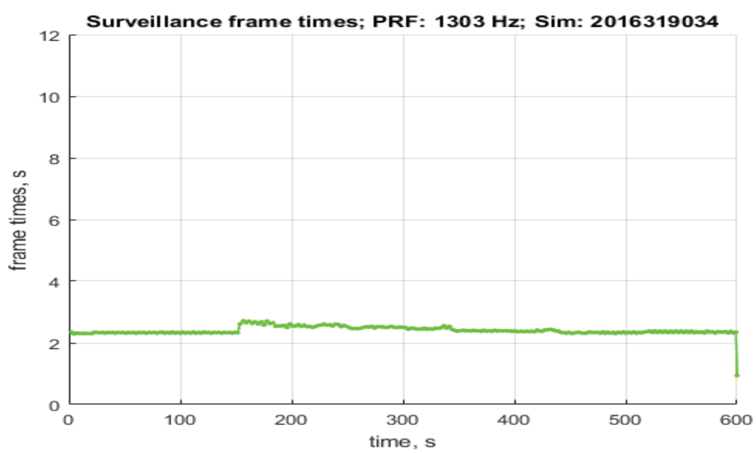
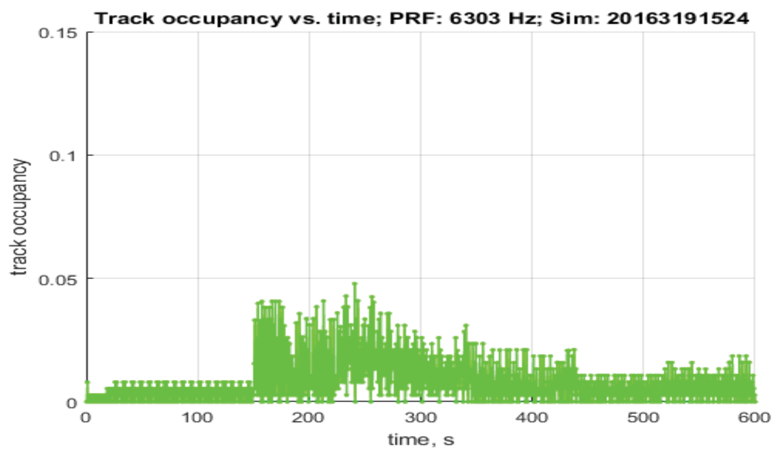


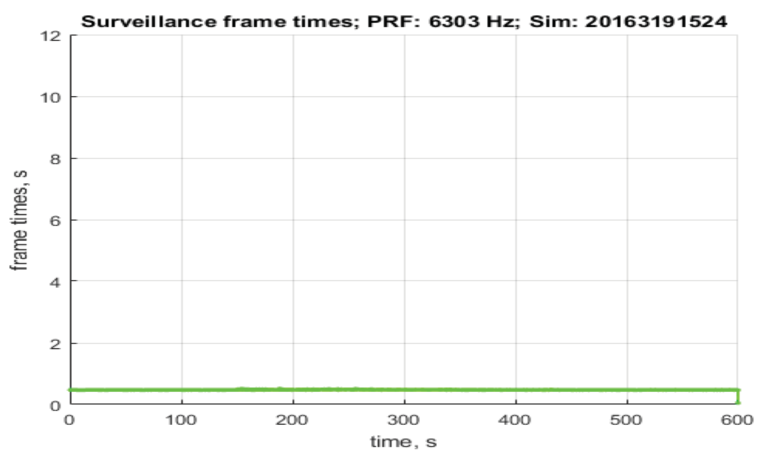
(c)

Figure 12: *Results using PRF of 1303 Hz. (a) Track completeness. (b) Track occupancy. (c) Frame time.*

(a)

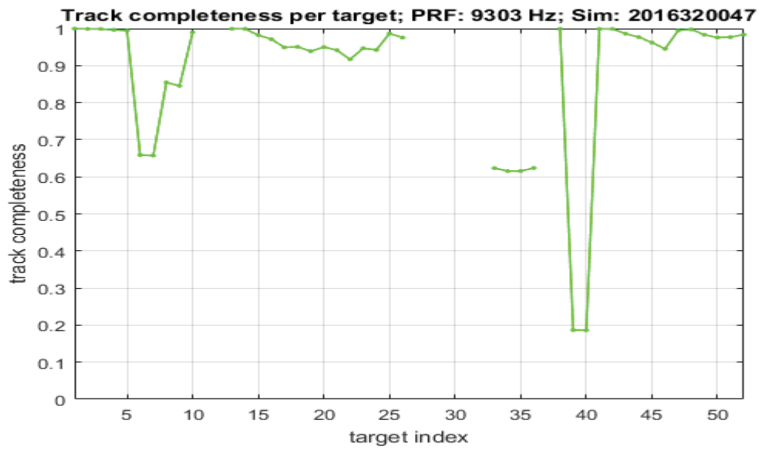


(b)

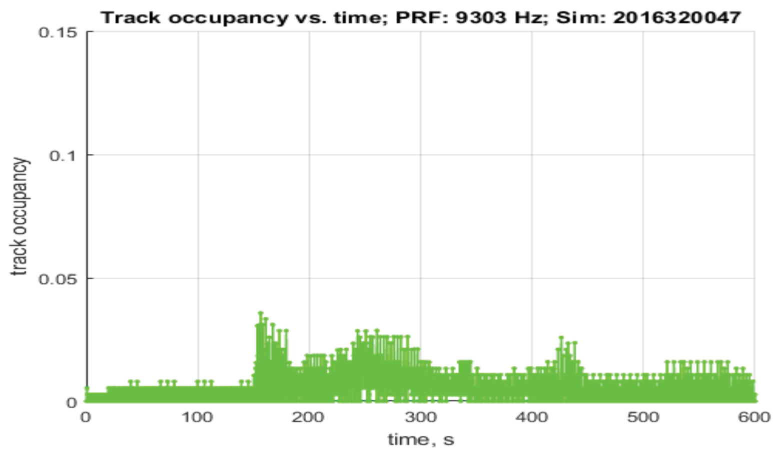


(c)

Figure 13: *Results using PRF of 6303 Hz. (a) Track completeness. (b) Track occupancy. (c) Frame time.*



(a)



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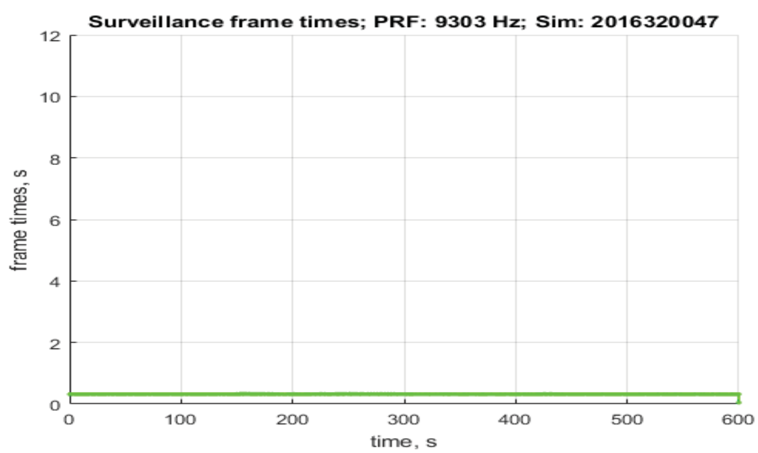


(c)

Figure 14: *Results using PRF of 9303 Hz. (a) Track completeness. (b) Track occupancy. (c) Frame time.*

As PRF is increased (and PW decreased), the track occupancy and frame times decrease as expected. The targets are therefore illuminated more times in the same time duration but with decreased target return power due to the shorter PW. Figure 15 shows the track completeness for all PRF values tested. One can see how some targets are tracked better with certain PRF values. In a distributed radar scenario, the combination of two or more appropriate PRF values was expected to improve track completeness for most of the targets tested.

Figure 16 shows the results of a two radar simulation using one radar with a PRF of 603 Hz and a second radar with a PRF of 9303 Hz. Figure 17 shows the results of a three radar simulation using one radar with a PRF of 603 Hz, a second radar with a PRF of 9303 Hz and a third with a PRF or 1303 Hz. A distributed type two radar configuration was used. Results seem to indicate that the track completeness is dominated by the highest PRF used with no clear benefit from the lower PRFs. Another test was performed using three PRFs of similar value so that one PRF would not dominate tracking but were different enough so that the ambiguity zones were different. This is more in line with the recommendations for multiple PRF choice by Skolnik (1990). Figure 18 shows the results of this three radar simulation using one radar with a PRF of 904 Hz (13E-5 s pulse width), a second radar with a PRF of 1017 Hz (11.6E-5 s pulse width) and a third with a PRF or 1130 Hz (10.4e-5 s pulse width). Results seem to indicate a small improvement over the single 903 Hz result and the single 1303 Hz result however either of the single 1017 Hz or 1130 Hz PRF radars may exhibit this result independently. This result would indicate no benefit from a multi-radar/PRF coordinated RRM simulation with the goal of improving track completeness.

After some analysis it was clear that to realize the benefit of multiple radars with different PRFs Adapt_MFR would need to be modified to use a central tracker with multiple independent radars rather than using coordinated RRM. This is because the algorithm used to select which radars the tracks are assigned to do not take into account ambiguity. Therefore a track could be assigned to a radar that would could attempt a track update during the period of time when the target was in an ambiguity zone. Some limited attempts were made to convert the tracker but this work was not completed to a usable state at the time of release of this report. The result is shown in Figure 19; however, the tracker modifications were not finished so this result is not of any significant value.

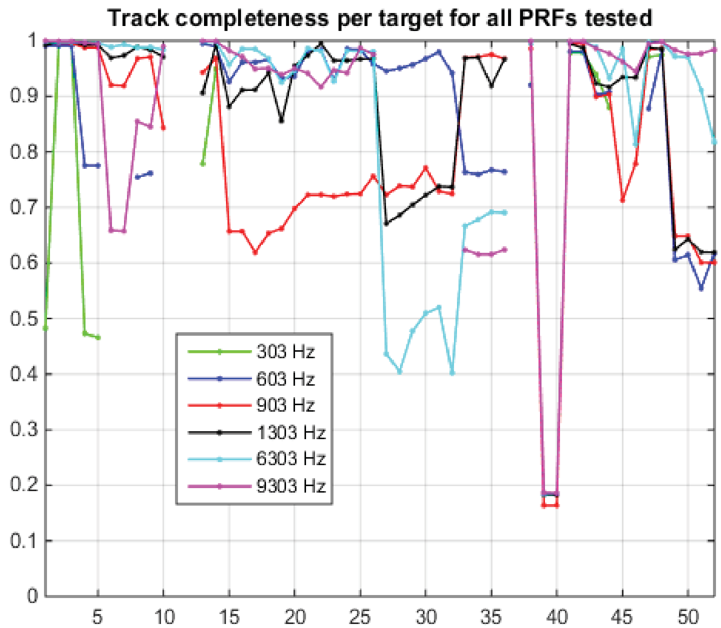
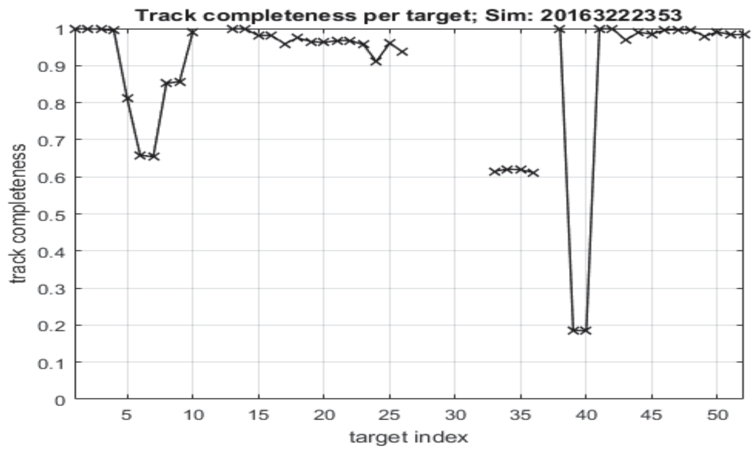


Figure 15: *Track completeness for all PRFs tested.*



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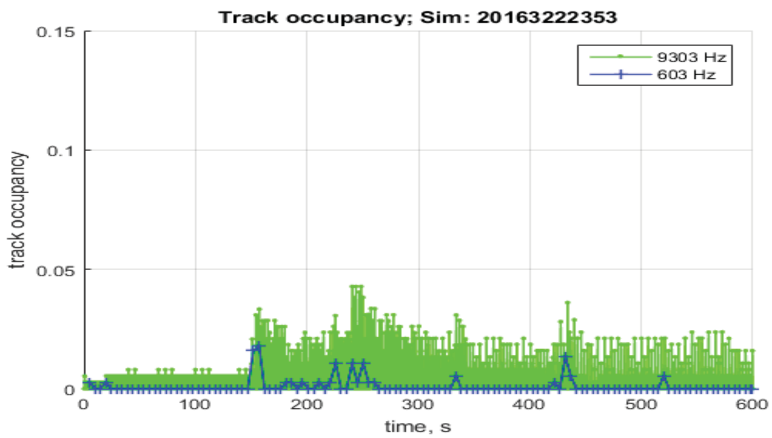

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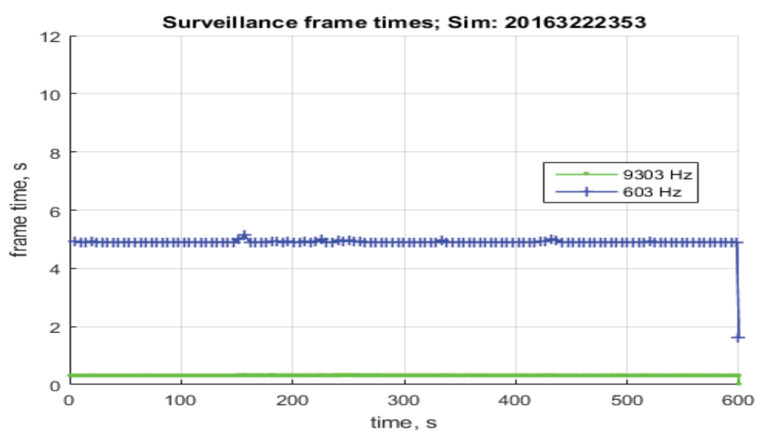
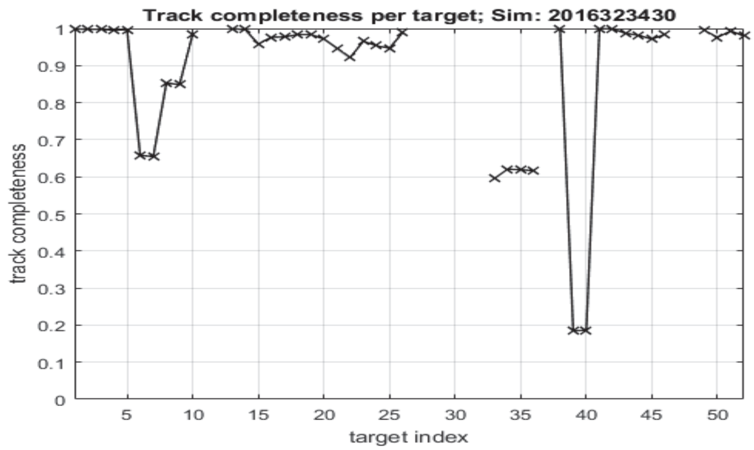
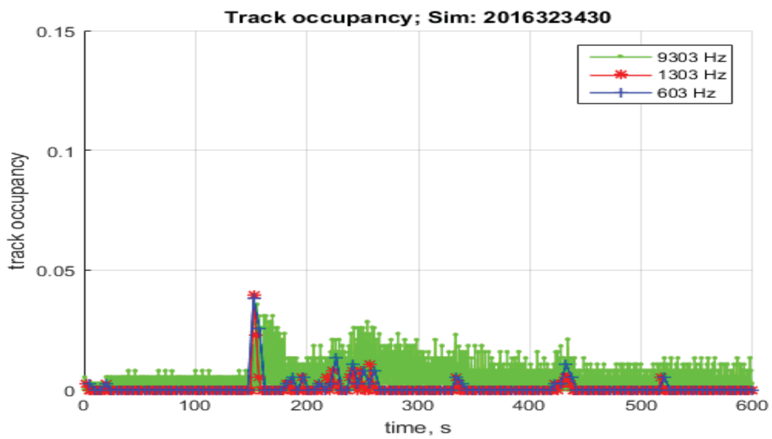


(c)

Figure 16: *Results using two radars with PRF values 603 and 9303 Hz. (a) Track completeness. (b) Track occupancy. (c) Frame time.*



(a)



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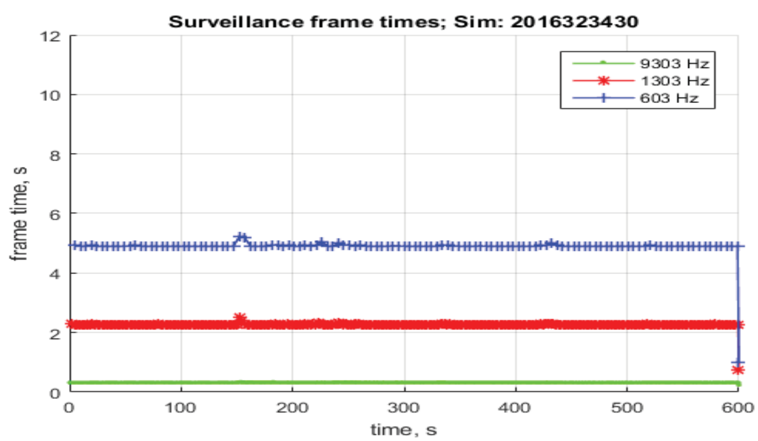

(c)

Figure 17: *Results using coordinated RRM and 3 radars with PRF values 603, 9303 and 1303 Hz. (a) Track completeness. (b) Track occupancy. (c) Frame time.*

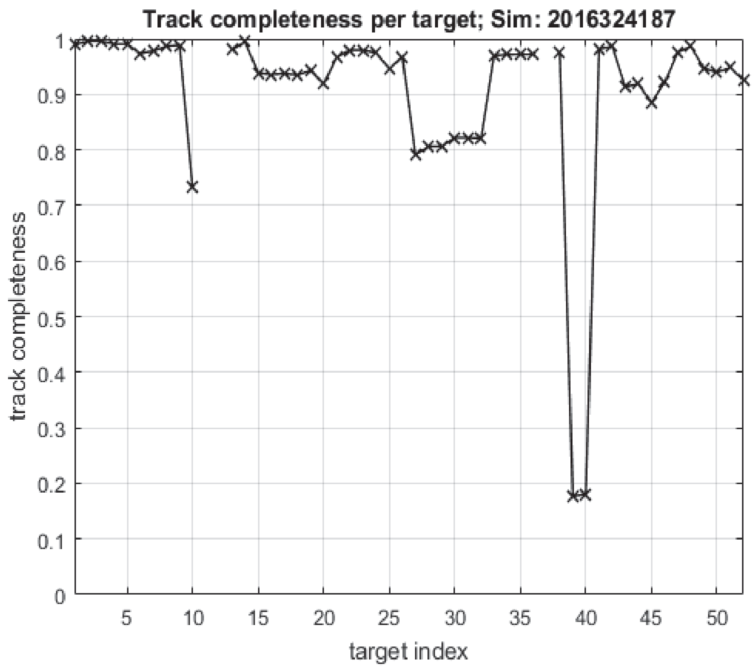

Figure 18: *Track completeness results using coordinated RRM and 3 radars with PRF values 904, 1017 and 1130 Hz.*

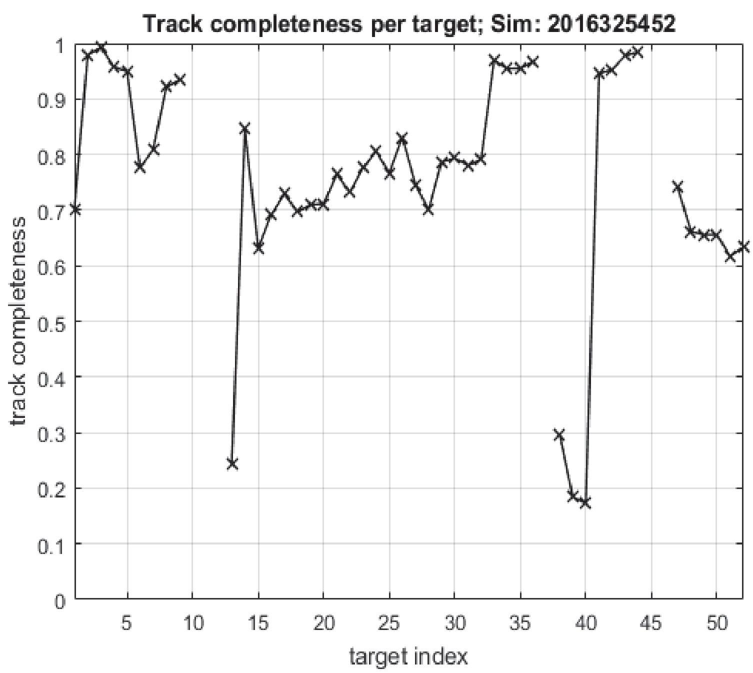

Figure 19: *Track completeness results using "modified" independent RRM and 3 radars with PRF values 904, 1017 and 1130 Hz.*

3 Target localization

This section describes the investigations into target localization in a distributed/multiple radar scenario for the purpose of resolving range ambiguity resulting from the use of higher PRF waveforms.

3.1 Methods researched/investigated

Skolnik (1990) describes using the Chinese Remainder Theorem (CRT) to calculate the true range from the several ambiguous measurements in a high PRF ranging situation using three PRF values. The PRFs chosen should be related by the ratios of closely spaced, relatively prime integers. For medium PRF values a set of seven or eight PRFs is recommended. These methods are described in the context of range ambiguity resolution in a multi-PRF system rather than for distributed radars however the strategies could be applicable for a centralized tracker that resolves ambiguous returns from several radars. In terms of choosing PRF values, Shukla (2009) gives some detail into PRF selection to avoid eclipsing loss (for airborne radars). Zhen-xing (1987) describes an extended CRT that is proposed to alleviate the sensitivity of the classic theorem to noisy data.

Lacoss (1987) describes distributed sensor networks utilizing two algorithms for tracking; a local estimation algorithm for updating tracks with local sensors using an extended Kalman filter and a distributed estimated algorithm combining tracks from multiple sensor nodes using only position and velocity estimates and covariance matrices. In the context of Adapt_MFR, this would be similar to many instances of the software running and tracking independently but also allowing for the input of tracking update data from other instances; essentially a de-centralized tracker. The software has no communication channel to simulate this functionality at this time (only communication channel delay effects and bit errors can be modeled).

In Chang (1985;1986) a distributed version of Joint Probabilistic Data Association (JPDA) algorithm which handles the problem of data fusion from multiple processors in a distributed sensor network is presented. In this scheme, each node first performs the tracking functions with the JPDA algorithm using the local sensor measurements and sends the processed results to other nodes. The receiving node then fuses the information from other nodes with its local information to arrive at a better estimate. Chong (1985;1986) go into the local processing and fusion processes in more detail. This is also a de-centralized tracker implementation.

Target localization performance can be improved using more radars or increased transmit power per radar however full system utilization may be inefficient and unnecessary. Godrich (2011) presents an interesting approach to optimizing system resource use including efficient power transmission and communication link utilization by radars through performance driven resource allocation schemes. This paper is perhaps outside the scope of this work but may provide insight into future advancements of the software.

There are many papers in the fields of Ultra Wide-Band (UWB) and Multiple Input Multiple Output (MIMO) radar that describe several interesting approaches to target localization that could be applied in some form in Adapt_MFR. A selection of these papers are listed in the Bibliography.

3.2 Problems with implementation in Adapt_MFR

The limitations of Adapt_MFR with respect to range and Doppler ambiguity were discussed in the previous PRF analysis in Section 2.4. The main issue currently preventing an implementation is that the detections passed to the tracker are not currently ambiguous so no ambiguity resolution is required or implemented. Some initial work was invested into implementing a form of range and Doppler ambiguity modeling but is not included in this version of the software (3.2.11). Two main types of simulations were run and analyzed to investigate the possibilities for implementing target localization in Adapt_MFR. They are described in Sections 3.2.2 and 3.2.1. Note that the coordinated RRM type of simulation using Adapt_MFR is currently modeled with a centralized tracker that accepts detections from multiple radars but assigns tracks to specific radars based on a combination of range and fuzzy logic priorities. Implementation of the de-centralized methods described in Section 3.1 would require a substantial reworking of the tracking structure and communication methods between the individual independent radars. Implementation of range and Doppler ambiguity and resolution by the existing centralized tracker or a new pre-tracker ambiguity resolver would initially be the preferred approach, although modifications are also required so that the tracker can work with multiple independent radars as discussed in Section 2.5.

3.2.1 Using multiple bursts per radar with different burst PRFs

Some simulations were performed using the approach of multiple bursts for one radar with each burst having a different PRF value. The idea here was that the single tracker would be updated with detections resulting from the different PRF values, representing returns from different radars utilizing different PRFs. This approach is limited however because only one PW value can be used for all bursts in one radar, limiting the range of PRF selection. This type of simulation also does not relate well to distributed radars. Because of this, limited time was spent on this approach in favor of the method described in Section 3.2.2.

3.2.2 Using multiple radars with different PRFs

In this method multiple radars with different PRF values per radar were used (each radar using one PRF value). Each radar has one appropriate PW value set. The primary goal of these tests was to determine if multiple different PRFs result in improved overall tracking for most of the targets tested. The two Figures (Figure 16 and Figure 17) in Section 2.5 resulted from this method. A secondary goal of this testing was to determine how to implement target localization if ambiguity was implemented in the pre-tracker stages and ambiguity resolution happened inside the centralized tracker.

In the current tracker implementation, it is possible to distinguish which detections come from which radar. This is similar to how it would be known which returns come from which radar node in a distributed system. For the purposes of range ambiguity resolution it would therefore be known which returns to use to do the ambiguity calculations as long as each radar was using one PRF. If multiple PRFs were used there would be no way to determine which PRF the return was associated with. Additionally, in a multiple target simulation it is not possible to determine which returns result from which target. If the returns have similar range and radial velocity but come from targets positioned at different bearing and elevation angles then additional steps to differentiate returns based on these angles may be necessary before ambiguity resolution takes place. Dianat (2013) describes angle of arrival (AOA) and line of bearing (LOB) use for target localization using triangularization. It may be possible to combine these methods to group returns by the received angles and then perform the range ambiguity resolution. When using multiple PRFs, an additional hurdle is that many returns will be received from the higher PRF radar before those of lower PRF radars. The tracker should probably attempt initial tracking on the ambiguous returns from the higher PRF radar and perform ambiguity resolution using target localization as additional returns come in from the lower PRF radars.

4 Usability improvements

Some new functionality was added to Adapt_MFR to improve usability during simulation and debugging and to avoid simulation errors due to improper parameter settings. The modifications are described in the following three sections.

4.1 Locking track update intervals

Description:
In the previous version of Adapt_MFR, the track update intervals for each track are updated during each simulation loop and could therefore change before the track was updated. Potentially this could result in shorter or longer update intervals than were initially commanded. It is now possible to lock the update interval once initially set and unlock the interval once the track has been updated.

Files affected:
.\Main\whats_next.m_adaptive.m - lines 60, 365, 677, 760, 1177, 1421:1423

4.2 User confirmation of select parameters before simulation execution

Description:
An information block is shown to the user immediately after the simulation starts which displays several of the variable parameters that are set in the code as opposed to the GUI. After reviewing the parameters values the user has the option to continue or end the simulation.

Files affected:
.\Main\adaptmfr_run.m - lines 915:939

4.3 Periodic simulation pauses to allow for temporary simulation interruption and debugging

Description:
At the beginning of each iteration of the main simulation loop, and based on a set time interval, the user is given the option to breakpoint the simulation. This allows the user to add or adjust breakpoints elsewhere in the simulation. Previously, if breakpoints were not set up before the simulation was started there was no way to breakpoint the simulation for debugging without exiting the simulation and starting over.

Files affected:
.\Main\adaptmfr_run.m - lines 974:986
.\Main\waitinput.m - MATLAB® file exchange BSD license function

5 Bug fixes

5.1 Invalid PRF and pulse width parameter combinations

A number of issues were encountered during the analysis and testing work. Most of these arose due to new parameter settings and/or input file types that were not previously tested with the current version of Adapt_MFR (3.2.11).

Description:
Previously it was possible for the user to input PRF and pulse width combinations that were invalid. It was possible for the user to input a PRF that resulted in a PRI shorter than an actual pulse width. The simulation would run to conclusion without error or warning. The software has been updated to detect upon simulation startup when the the PRI is shorter than the total pulse width of all pulses in a burst. Upon detection the user is shown a warning and the simulation ends.

Files affected:
.\Main\adaptmfr_run.m - lines 206:241

5.2 Target input file structure

Description:
The software had been modified to handle multiple target input file types in the past. The software sometimes has problems detecting the target type upon load and/or reload of the parameter file. Some additional target type detection logic was added to resolve this.

Files affected:
.\Main\adaptmfr_run.m - lines 468 & 494:507
.\Gui\cbPlaneView.m - lines 112:113 & 121:127 .\Main\missile_lookup.m - lines 62:103

5.3 Coordinated radar resource management type logic

Description:
Previously when the *adaptive_time_balancing* flag was set to zero the *coordinated_management_type* was automatically set to 3 (independent radar/tracker mode) and the *communication_channel_always_on* flag was set true. This was modified so that the *communication_channel_always_on* flag is set true if *coordinated_management_type* is of type 3, regardless of time balancing type. The *max_com_delay_seconds* value is also set to 0 if *coordinated_management_type* is of type 3, which overrides the GUI setting.

Files affected:
.\Main\adaptmfr_run.m - lines 197:203

5.4 Detection elevation scan number

Description:
The *radar.realDet.el_scan_num* variable was incorrectly set to a previously stored value rather than

the currently active radar face, which resulted in errors in a multi-radar simulation. The software was modified to correct this.

Files affected:
.\Main\adaptmfr_run.m - lines 2739 & 2741
.\Main\add_false_alarms.m - lines 229 & 327 & 383 & 492
.\Main\update_scheduler.m - lines 102 & 161 & 246 & 290 & 390
.\Main\set_scheduler.m - line 110

5.5 Result output file renaming

Description:
A bug was found which would prevent the output files from being renamed under certain file conditions (renaming is based on date and time parameters at the end of the simulation). The simulation would end prematurely and some output files were not saved. A catch statement was added to allow the simulation to finish and a warning is displayed regarding the offending file.

Files affected:
.\Main\adaptmfr_run.m - lines 3246 & 3252:3254 & 3260 & 3266:3268

5.6 Horizon test angle

Description:
Calculations to determine if targets are hidden below the horizon were using an improper angle (the elevation angle instead of the horizon angle). The calculation was updated with the proper angle.

Files affected:
.\Main\horizon_test.m - lines 34:36
.\Main\horizon_test2.m - lines 15 & 19

5.7 Radar assignment logic change

Description:
During certain simulations, tracks were always assigned to the same radar in a multi-radar scenario when the fuzzy logic priority values and the track range to radar resulted in no particular preference for radar assignment. Previously the track was always assigned to the first radar in this case. This is a tracking problem when one radar has a significantly lower track update rate and/or PRF and the track is always assigned to that radar. Some additional logic was added that causes the track assignment to be transitioned back and forth between radars based on a set interval. If fuzzy logic priority values and/or the track range to radar result in a radar assignment preference this assignment transition method is not used.

Files affected:
.\Main\whats_next.m_adaptive.m - lines 1011:1026

5.8 Obsolete MATLAB® functions or function options

Description:
In the more current versions of MATLAB®, some functions used by Adapt_MFR have become obsolete or their input options have changed. The simulation would not execute properly to completion in these cases. These function calls have been updated to work with current versions of MATLAB® (2014b/2015b).

Files affected:
.\Gui\cbPlaneView.m - lines 219, 263, 284 & 298
.\Main\rflct_land.m - lines 73, 77 & 81

6 Execution speed improvements

The software was modified in several places to improve execution speed. Three general methods were implemented which are described in the first three of the following sections (6.1 - 6.3). Three specific modifications were made that, although have minimal impact individually, can have a large impact on execution speed when executed during many if not all iterations of the main simulation loop. They are described in the last three sections (6.4 - 6.6).

6.1 Replacing *find(...)* function calls with logical indexing

Description:
Replacing calls to the *find(...)* functions with logical indexing offers an execution speed improvement and is commonly suggested by MATLAB®. In many cases using *find(...)* with an *is...(x)* function to index an array is not necessary. The *is...(x)* function returns a logical array which can in turn be used to directly index the array as in the following examples.

ex: use *array(isnan(array))=0;* instead of *array(find(isnan(array)))=0;*
OR use *array(array >4)=0;* instead of *array(find(array >4))=0;*

This type of modification was done in the listed files.

Files affected:
.\Main\adaptmfr_run.m - lines 710:712, 781, 789:790, 1178, 1180, 1184, 1210 & 1420
.\Main\whats_next.m_adaptive.m - lines 1111:1122, 1132:1133, 1143:1152, 1159:1170, 1233, 1228 & 1294

6.2 Replacing loops with vector calculations

Description:
Loops add overhead in general and should be replaced by vectorized code where possible as shown in the following example.

ex: use *array=array+1;* instead of *for i=1:10; array(i)=array(i)+1; end;*

More complex varieties of this type of modification were done in the listed files.

Files affected:
.\Main\centroid_detections.m - lines 221:247 & 300:301
.\Main\horizon_test.m - lines 9:28

6.3 Circumstantial calculation bypass

Description:
In many parts of the code several *if* statements were checked and many "zero-change" calculations were being performed. This occurred with a simulation parameter was set in a way so that the

section of code was not required to be performed (because it had no affect on the outcome). In these cases an *if* statement was applied to the code block and was used to evaluate the need to execute the code based on the higher level simulation parameter. This speeds up code execution by avoiding unnecessary calculations and function calls.

Files affected:
.\Main\intersects_m.m - lines 125:137
.\Main\whats_next.m - lines 274:278 & 312
.\Main\whats_next.m_adaptive.m - lines 202:206, 246, 456:461, 508 & 906:917
.\Main\trajctry.m - lines 121:130, 203:216, & 276:297

6.4 Replacing the calculation *inv(A)*×*b*

Description:
The statistical distance calculation

dij = yij_flags×inv(S) × yij_flags.';

was replaced by the equivalent but more accurate calculation

dij = yij_flags×(S\yij_flags.');

The change avoids the call to the *inv(...)* function and instead uses a left matrix divide. It also avoids warnings due to bad scaling of results from the *inv(...)* function. This code is executed very often so execution time is saved.

Files affected:
.\IMM_Tracker\models\compositegating.m - line 98

6.5 Replacing the comparison *strcmp(upper(str),'Y')*

Description:
The user input comparison

strcmp(upper(str),'Y')

was replaced by the equivalent but faster

strcmpi(str,'Y').

strcmpi ignores case so there is no need to make the nested *upper* function call. This code is executed during every simulation loop so execution time is saved.

Files affected:
.\Main\adaptmfr_run.m - line 2994

6.6 Replacing *if length(hit_ndx) >0*

Description:
This code checks if the target detection hit index is empty.

if length(hit_ndx) >0

was replaced by the equivalent but faster

if isempty(hit_ndx).

This code is executed during every simulation loop so execution time is saved.

Files affected:
.\Main\adaptmfr_run.m - line 1184

7 Conclusions

This report summarized the work done under Task 7 of Contract W7714-125424/001/SV. DRDC Ottawa has contracted C-CORE for software support services relating to the analysis of pulse repetition frequencies (PRF) for distributed radars. Analysis and testing was performed using both single radar and multi-radar simulations with the Adapt_MFR simulator. In particular, there was an interest in implementing target localization to resolve range ambiguity at higher PRFs.

The main purpose of this work was to analyze the PRF trade-offs with respect to range and Doppler ambiguities and to characterize/implement target localization for distributed radars to resolve range ambiguity at higher PRF values.

Several Adapt_MFR simulations were performed using multiple radars with different PRF values and the shared central tracker. Results seem to indicate that the track completeness is dominated by the highest PRF used with no clear benefit from the lower PRFs. It is suspected that the main contribution to this result is the much higher scan rate from the high PRF dominating the tracking and the few contributions from the lower PRFs have little impact. Additionally, when using coordinated RRM, the algorithm used to select which radars the tracks are assigned to do not take into account ambiguity and therefore a track could be assigned to a radar that could attempt a track update during the period of time when the target was in an ambiguity zone. Adapt_MFR should be modified with an option to use a central tracker with multiple independent radars as an alternative to coordinated or independent RRM.

It has been determined that Adapt_MFR cannot currently support/simulate target localization when using multiple radars due to the limited range and Doppler ambiguity modeling and the structure of the centralized tracker when using multiple radars and/or multiple bursts per radar. The tracker could be restructured into a de-centralized form to implement some of the target localization methods investigated; however, it would require extensive work and it may be preferable to implement range and Doppler ambiguity in the pre-track software and modify the current centralized tracker to handle ambiguity resolution using target localization instead. Some methods were researched as described in Section 3.1 and some hurdles to implementation were described in Section 3.2.1.

8 Recommendations

It is recommended that some of the hard coded global variables, especially ones frequently modified by the user, be added to the GUI to improve the efficiency and accuracy of the simulation run. A block of parameters settings is currently displayed at simulation start up to allow the user to verity values and exit the simulation if necessary. Adding these variables to the GUI would be a cleaner solution and possibly avoid simulation input error.

As mentioned in the previous report, the *get_fuzzy_priority* function can sometimes return track priorities greater than one. This behavior was observed for one target during a short duration of time in one of the scenarios and is repeatable. Investigation into this anomaly is still recommended.

The communication channel bit errors are currently randomly generated and the actual track observation values are not modified with bit errors. This should be added in future work to represent true communication bit error simulations, especially for distributed radars scenarios.

It was expected that the differing PRFs used in a multi-radar simulation would result in improved target detection and consequently track completeness due to greater target return power outside the unambiguous range and Doppler zones. However, no significant track completeness improvement was observed. When performing track assignment to specific radars in coordinated RRM mode the tracker does not currently use knowledge of ambiguity zones and can assign tracks to the radar that has a PRF which positions the track in an ambiguity zone. This could result in a lost detection and lower track completeness. Some limited work was done to model a central tracker with multiple independent radars but several tracker modifications are still required. Implementation of a form of range and Doppler ambiguity modeling is in rudimentary stages. Additional effort should be invested into this research which will, in turn, support the implementation of target localization for range ambiguity resolution in Adapt_MFR.

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10 List of symbols/abbreviations/acronyms/initialisms

Adapt_MFR Adaptive Multifunction Radar
CRT Chinese Remainder Theorem
DRDC Defence Research & Development Canada
IMM-NNJPDA Interactive Multiple Model Nearest Neighbour Joint Probabilistic Data Association
JPDA Joint Probabilistic Data Association
MFR Multi-Function Radar
PRF Pulse Repetition Frequency
PW Pulse Width
RRM Radar Resource Management
SIR Signal-to-Interference Ratio
SNR Signal-to-Noise Ratio