RANGE/DOPPLER AMBIGUITY RESOLUTION
FOR MEDIUM PRF RADARS

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RANGE/DOPPLER AMBIGUITY RESOLUTION FOR MEDIUM PRF RADARS

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ABSTRACT

RANGE/DOPPLER AMBIGUITY RESOLUTION FOR MEDIUM PRF RADARS

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Range and Doppler measurement of targets for medium PRF radars is handicapped by folding and blind regions. This requires use of multiple PRFs and a resolver algorithm. The aim of the thesis is to develop various algorithms for the task and estimate their performance. Four different range and Doppler resolver algorithms and a test software is developed by using Matlab ® GUI and their performances due to the selected radar parameters in a multi- target environment are examined.

Keywords: Radar, Doppler, Range, Ambiguity Resolution, Medium PRF, Algorithm, Simulation

ÖZ

ORTA PRFLİ RADARLARDA MENZİL/DOPLER BELİRSİZLİĞİNİN ÇÖZÜMLENMESİ

Çuhadaroğlu, Burak

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Orta PRF radarlarında menzil ve dopler ölçümleri katlanma ve kör bölgeler nedeniyle sorunludur. Bu birden fazla PRF kullanılmasını ve bir belirsizlik çözme algoritmasını gerektirir. Tezin amacı bu görev için değişik algoritmalar geliştirilmesi ve başarımlarının kestirilmesidir. Dört farklı menzil ve doppler çözme algoritması ve bir test yazılımı Matlab ® GUI kullanılarak geliştirilmiştir ve bunların çok hedefli ortamda radar parametrelerine göre başarımları incelenmiştir

Anahtar Kelimeler: Radar, Dopler, Mesafe, Belirsizlik Çözümlemesi, Orta PRF, Algoritma, Simulasyon

To the memory of my grandfather Cemal Çuhadaroğlu , to my father Selahattin Çuhadaroğlu and my mother Selvi Çuhadaroğlu.

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INTRODUCTION

1.1 MPRF RADAR PROBLEM

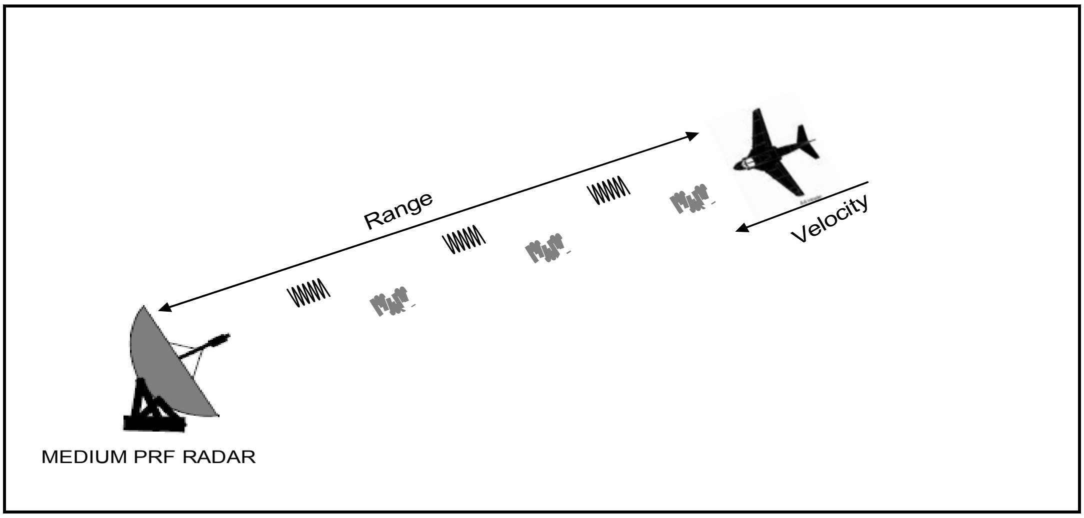


Figure 1 MPRF Radar and Target

The radar systems use different Pulse Repetition Frequencies (PRF) that are appropriate for range and Doppler detection. The used PRF values are classified as Low PRF, Medium PRF (MPRF), High PRF with respect to their frequency level.

For range detections, the main parameter is the maximum unambiguous range (Runamb) and it is the range that the target occurs as "second time around" echo or arriving echo after the transmission of the next pulse. This is the maximum unambiguous actual range that can be detected. It is given by the relation;

$$R_{unamb} = \frac{c}{2 \times PRF} \quad (1).$$

It is clear that, for a large unambiguous range, Doppler type radars must operate at a Low PRF.

The other main parameter is the unambiguous velocity. The maximum unambiguous velocity for a PRF the and defined as (2).;

$$v_{unamb} = \frac{\lambda \times PRF}{4} \quad (2)$$

For detecting higher velocities, higher PRF values should be used by the operating system.

In some applications, such as military radars or airborne radars, the system requires both range and Doppler information. For providing these, usually medium PRF (MPRF) radars are used. However, MPRF is useful for both range and Doppler detection; it has the disadvantages of ambiguities. The ambiguities are defined in the next section and a table for comparison of PRFs is given below [1] :

Table 1 Comparison of MTI and Pulse Doppler Radars

Comparison of MTI and Pulse Doppler Radars				
	Ambiguous Range	Ambiguous Doppler	Advantages	Disadvantages
MTI - Low PRF	No	Yes	-Ability to sort the clutter from targets as range. -Front-end STC suppresses the sidelobe detections and reduces the requirements of dynamic range. -No range ghosts.	-Multiple Blind speeds causes low Doppler visibility. -Poor slow-moving target rejection. -Unable to measure radial target velocity.
Pulse Doppler Medium PRF	Yes	Yes	-Good performance at all target aspects. -Good slow moving target rejection. -Measures radial velocity. -Less range eclipsing than in high PRF.	-Range ghosts. Sidelobe clutter limits performance. -High stability requirements due to range folding.
Pulse Doppler High PRF	Yes	No	-Can be side lobe clutter-free for some target aspects. -Single Doppler blind zone at zero velocity. -Good slow- moving target rejection. -Measures radial velocity. -Velocity-only detection can improve detection range.	-Side lobe clutter limits performance. -Range eclipsing. -Requires high stability requirements due to range folding. -Range ghosts.

1.2 DOPPLER AMBIGUITIES

The unambiguous velocity is defined as formula (2) . For higher PRF, the system can detect higher unambiguous velocities.

Radar operating at fixed PRF also produces ambiguities in radial velocity that are separated by

$$\frac{\lambda \times PRF}{2} \quad (3)$$

due to the pulse-burst waveform ambiguity function. This may be a problem when the radar clutter has a radial velocity spread greater than the radial velocity ambiguity. In such cases, the clutter at the ambiguous radial velocities is added to the zero-velocity clutter, which may significantly increase its magnitude.

This velocity ambiguity in the Pulse-Doppler radar is a big problem, because the Doppler Shifts crossing the next line in the frequency spectrum will be aliased. The solution of this problem is increasing the PRF, but this increases the spacing between the adjacent lines in the transmitted spectrum and allows greater shifts before aliasing occurs. For military radars applications generally PRFs of several hundred kilo hertz are used for detecting high speed closing targets. But there is a limitation for PRF increment before range ambiguity may occur. For resolving this ambiguity, high PRFs is used by the transmitting various pulse packets that are having different PRF-values. But in this case, as the correct velocities remain fixed, all introducing of "ghost velocities" by aliasing change occurs when the PRF values are altered. The maximum unambiguous range and maximum unambiguous velocity dilemma is given in the figure below [2] :

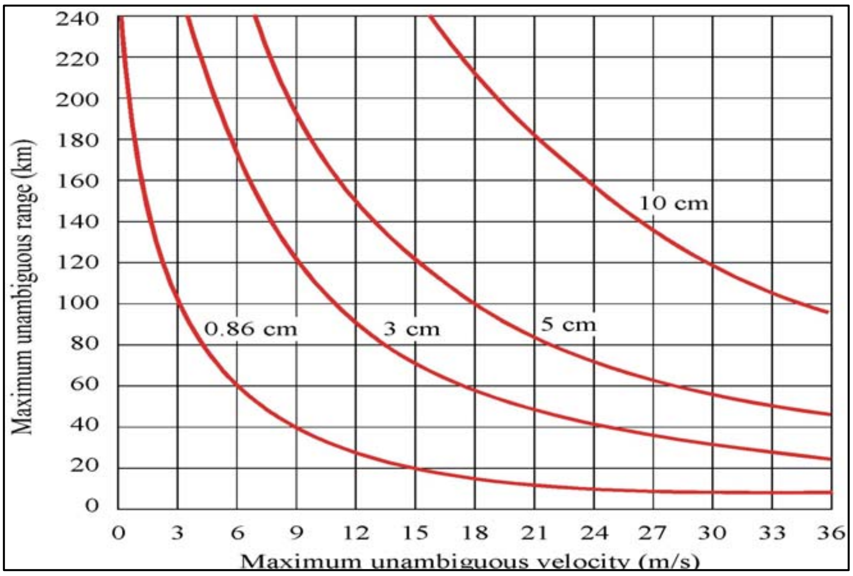


Figure 2 Range and Velocity Ambiguity Dilemma

In order to eliminate the Doppler ambiguities, the detection of targets with high speed require high PRF rates in radar operation.

1.3 RANGE AMBIGUITIES

A signal returning from a target located at a range greater than

$$\frac{c \times PRI}{2} \quad (4)$$

, will reach the receiver after the next pulse has been transmitted. It will be interpreted as a target return from the latter pulse, and as having a range much shorter than the targets actual range. This type of range ambiguity is often called a second-time-around return. The targets at the longer ranges may even produce a third, fourth or higher multiple-time-around returns with respect to the used PRI and targets distance. The radar PRF is selected with respect to the unambiguous range where the range is long enough to satisfy the radar systems operational requirements. Usually long range radars operate with low PRF for this limitation. The dilemma for a 5cm wavelength radar is given in Figure 2

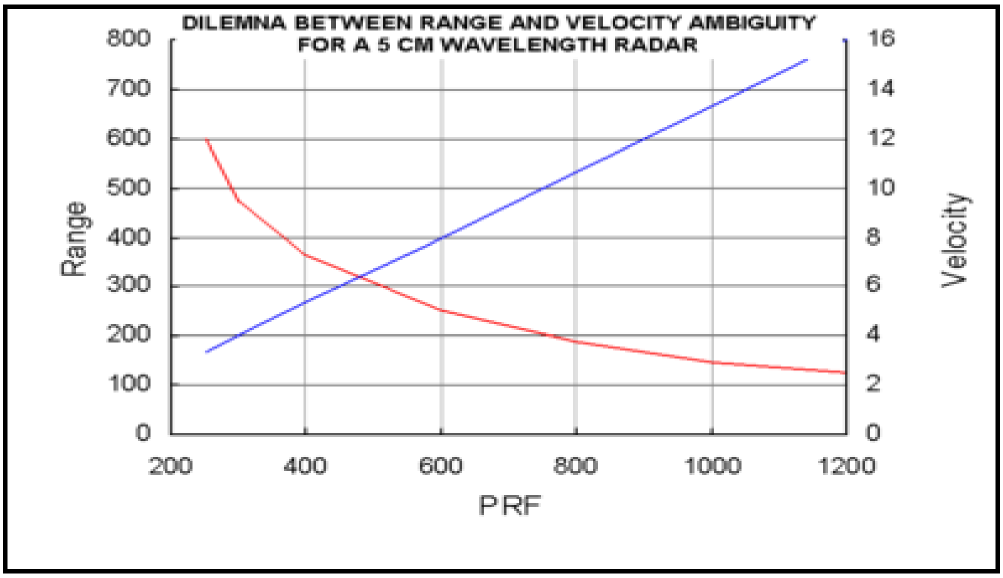


Figure 2 Dilemma Between Range and Velocity Ambiguity

For a PRI of 100e-6 sec, or the PRF of 10 MHz, the PRI is 0,1 ms, the unambiguous range is 15Km. The return from a target at a range of 20 km would appear to have a range of 20-15=5 Km .A target at a range of 40 km would appear as a third-time- around return to have a range of 10 km. So we can say that the detected signal will be

$$\text{Received Signal=Actual Range mod}_{(\text{Unambiguous Range})} \quad (5)$$

The transmitted and received signals and range foldings are shown in the Figure 3:

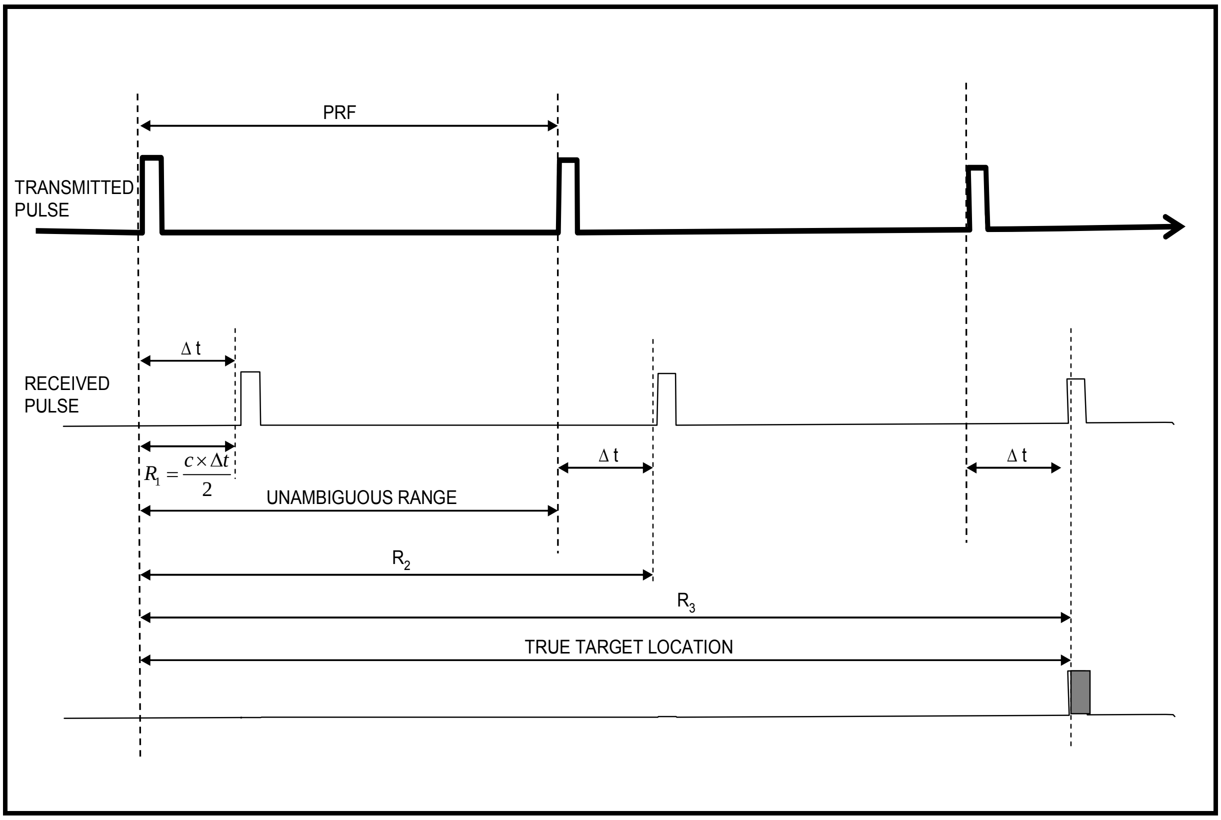


Figure 3 Unambiguous Range and Ambiguous Ranges

The problem with multiple-time-around returns occurs when these returns are not estimated and the target range is misinterpreted. One of the technique to mitigate multiple-time-around returns is changing the interpulse interval from pulse to pulse. This method is called as jittering the PRF. By using this technique, the apparent range of the multiple-time-around return changes from pulse-to-pulse. When the range is measured from the correct transmitted pulse, it remains fixed.

Another technique is changing the transmitted signal frequency from pulse-to-pulse. After observing the received signals frequency, the received signal may then be coupled with the transmitted pulse . This method can not be used when coherent processing is used on successive pulse returns [4] .

For detecting of targets located at long ranges and moving with high velocities, the radar system can be unable to give both unambiguous range and Doppler information's. To solve this problem the systems generally use multiple PRF s, that are transmitted sequentially in a dwell time period or that can be transmitted in due to the result of previous scans detection results for certain detections.

1.4 LITERATURE STUDIES AND OTHER ALGORITHMS ON RANGE AND VELOCITY AMBIGUITY RESOLUTION

A medium PRF radar seems to be the convenient device if range and Doppler measurements are to be performed simultaneously. This choice however leads to ambiguity in both measurements and hence the necessity of some method to resolve ambiguity. Various ambiguity resolving algorithms exist in technical literature. Many of them tackle with the range ambiguity problem alone. Quite a few techniques are suggested for handling ambiguities both in range and Doppler. The algorithms may be implemented on hardware or software. This study deals with resolving both ambiguities in the software domain.

For resolving ambiguities of MPRF radars, methods based on Chinese remainder theorem (CRT) are frequently used. There are various types of algorithms for CRT. The study done by Skillman and Mooney is based on solving problems by selecting mutually prime PRFs [5]. Later this system is expanded by Hovanessian for the non mutually prime PRF values.[6]. In addition Hovanessian's algorithm, there are also other proposed algorithms that use extended CRT; one of them is done by Zhen-Xing [7], that is valid for non-mutually prime and has simplicity in computational operations when compared to the canonical CRT, for range detections. The disadvantage of this method is, in case of having a measurement error; the result error will be very large.

There are some other studies based on the CRT for resolving Doppler ambiguity by using the Discrete Fourier Transform (DFT) output of two operated PRF's, A condition on the relative values of the two PRF's is derived to account for the finite and overlapping bandwidths of the DFT filters. The third PRF is used to identify the corresponding declarations of a particular target observed in the three PRF's. Range ambiguities are then resolved to confirm the targets and to eliminate any false detections. Through the process, the algorithm points out the possible blind-speed targets. A fourth PRF is transmitted to extract the targets that are blind in any of the first three PRF's detections [8].In this method the pulse trains are assumed to be at the same frequency. Expansion of this method for systems using pulse trains that are using different frequencies is studied [9].

The clustering algorithm is more advantageous for error. This method uses the minimum or average squared error criterion for operation. It is done by unfolding the measurements by using their PRFs and creating all the possible hits. Then it compares the all sets and groups with respect to their differences and decides by finding the unfolded value that has the minimum squared error.[10]. The detections of groups is also done by using maximum –like hood criteria [11].

The residue lookup table is another technique that first selects one of the PRFs residue as reference and calculates the difference of them with the other PRFs residues. Then checks them from a look-up table that is created before and that also includes the results for the case of blind areas that are can not be observed. By taking into account of probable redundancy error, this method is successful against the measurement errors [12].

When compared to the CRT, it has superior performance for high and medium PRFs. Although it has a good anti-error ability, it needs much computational work for calculations.

There are some other techniques offered for resolving both range and Doppler ambiguities that are based on selecting PRFs by some criteria's. Selection criteria's and the limitations were studied. The method uses maximum-like hood criteria and creates a lattice in a space that has dimension 1 less than the number of used PRFs and creates a lattice. The solution is given as the closest point to the lattice and the density of the lattice is also defined. [13] Using the skyline graphics is also another technique and it is similar to this technique.[14] But this system fails for other sets of PRFs where generally altering PRF values is a necessity for detection.

Another technique for resolving Doppler ambiguity is, grouping the PRFs into pairs. Suitable PRF values are selected for providing easy calculations for each group [15]. This method is developed later and the selection of optimum PRFs is also studied [16].

In literature, there are studies based on minimizing the blind areas in Doppler-range space and providing optimal PRF set selection [17].

However the selection of PRF values is out of the scope of this study, one may find details also in some radar books [18].

The study on codes that increasing the cross-correlation between the pulse trains is another technique and it has the limitation such as being of number of pulses equal to the length of the codes [19].

Another approach based on this study is using multiple PRFs at constant frequency and coding every pulse in pulse trains by random phases. Coding of the pulses that are at same frequencies by different phases allows coherent integration and this provides resolution for the range ambiguity. The solution is based on the optimal coherent filter calculations and considering the folding of the clutters. The study also includes the descriptions of a receiver that prevents the cross-correlation between the units that use phase coding [20].

The coincidence algorithm is another one that is computationally intensive for even small number of targets. It operates by taking the target returns in a single PRI and repeating them until the maximum range may be present. This process is repeated for all PRIs. The results are overlaid and if the targets place is true, it will appear in the same place for all PRIs. The same steps are fallowed for Doppler resolution .The procedure has constraints on PRF selection.

1.5 OBJECTIVE, LIMITATIONS AND PRODUCTS OF THIS STUDY

The usage of MPRF has the cost of ambiguities in range and Doppler. The aim of this study is creating new algorithms for resolving both range and Doppler ambiguities caused when used MPRF and testing these algorithms performances by using different system parameters.

The software is developed in Matlab® language by using version 6.5 . In addition to the algorithms and functions, also a Matlab® GUI is designed for allowing the user entering the test parameters, viewing the results of tests and testing the blind velocity and blind range of the PRF to be used. Four different algorithms are developed and they are tested by changing the system parameters and their performance results are observed with respect to the studied parameters

CHAPTER 2

2. PROBLEM DEFINITION AND THE APPROACH

In this study, we assume the radar is a search radar which has time budget limitations, due to the mechanical azimuth scan The system requires rapid algorithms for commenting on the received signals and decision. The radar can dwell on target at most for three PRIs. Probably the it will send a PRI and if there is anything worth resolving it will send the second and the third.

It is assumed that a proper 3 PRI set is provided by some other algorithm (off line, as a precalculated set of numbers). The observed range is covered at least by two of these PRIs.

Although the approach is applicable to a variety of radars, a typical scenario is chosen to limit this investigation. According to the scenario, the system is a pulsed Doppler radar for range and velocity detection. The system can only scan an observed cell for once and there may be no chance of a new scan for increasing the accuracy of detections.

The selected system parameters are given below:

Pulse Repetition Intervals = [100 130 160] x1e-6 sec

Instrumented Range = 75000 m

Minimum Detectable (Blind Region) Range =3000 m

Maximum Detectable Range = 40000 m

Length Of Resolution Cell =10 m

Range Error = 0.3

Maximum - Or + Speed of Targets Observed =400 m/sec

Minimum - Or + Speed of Targets Observed =30 m/sec

Operating Frequency = 1 e9 Hz

The Doppler Bin Number for Each PRI = [16, 16, 16] (8 Negative And 8 Positive Bins)

Probability of False Alarm= 1 e-6

Probability of Detection= 0.95

Zero Doppler Bin= 16’ th bin

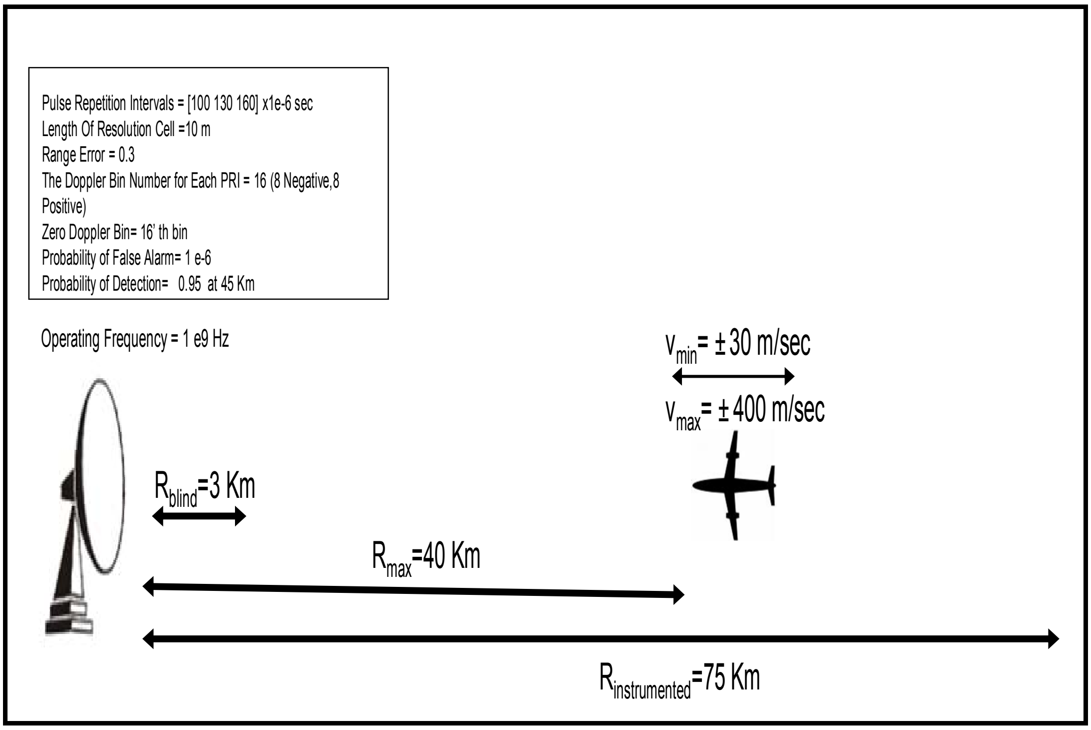


Figure 4 Selected Scenario and Parameters

Also for the targets located at the range 45000 m the probability of detection is given as 0.95.

The PRI set is chosen such that PRIs cover the blind zones of other PRIs . However the set is given, the software is designed by the flexibility of selecting different PRI values with different number of PRI sets. The targets closer than 3000 m are defined as blind an undetected and as the targets located further than 40000 m, their probability of detection also decreased to less than 0.95, due to their ranges.

Probability of detection depends on radar, detection method, terrain and the targets. Although radars are designed to maintain constant probability of false alarm, for each range cell probability of detection varies. It is not feasible to take into account however billions of possible scenarios. Therefore a crude Pd variation on range is assumed with a primitive detection mechanism based upon radar equation. Radars are usually designed to yield a minimum Pd at a maximum range of interest. This improves when the target is nearer. This variation is modeled roughly by a simple approach.

In the tests, the targets located at a distance further than 75000 m are defined as not observed. The range resolution cells are given 10 m, so the range values are divided by this value and their equivalent range bin numbers are found from these values. The targets having velocities less than minimum speed or higher than maximum speed are also accepted as undetected. The probability of false alarm is 1 e-6, so the system generates false detections by this probability and sometimes ghosts or false target decisions are occurred. The Doppler bin number is given as 16 where the accuracy of Doppler detection is mainly based on number of Doppler bins. The zero Doppler bin is assigned as 16 'th bin so the values corresponding to this bin are assumed to be 0 where this bin also corresponding to blind velocity for the used PRI .

Usually like-hood approach is used in the algorithms. The PRI hits are matched and ordered for simplifying the process. In algorithm 1, range calculation is done only searching the last PRI hits in the other PRIs. The velocity is calculated by searching every used PRIs unfolded velocities in each other. The pair combinations of used PRIs are searched in the other PRI . The decision is done by using merits, that are created due to hits like-hood.In algorithm 2, The same approach is applied to range calculation. The velocity calculation is done by unfolding the hits and concatenating them with the searched hits and sorting them. Then each array element is subtracted from each other. The ones with smallest difference are selected as final hit. The same approach is applied to range and velocity in algorithm 3. In algorithm 3, every unfolded hit is searched in every unfolded hit. The hits are not matched and ordered.

CHAPTER 3

3.COMPUTER PROGRAMS -DESCRIPTION AND INTERFACE

3.1. THE USER INTERFACE FIGURES

The simulator test program is developed by using Matlab version 6.5 and it is based on the assumptions mentioned. Matlab is preferred due to its higher performance in statistical applications. Also user interfaces are created by using Matlab GUI utility. Usually small .m files are created for flexibility and re-use of functions in different algorithms.

In this study, four different algorithms are tested by using the GUI named Configurationpage and their results are displayed by using the GUI named as Resultspage. There is also a third GUI named as PRI_PRF_PERFORMANCE for testing and determining the blind range and blind velocities within the interested range and velocity intervals for the selected PRF or PRF set . The GUIs are described below:

3.1.1 THE CONFIGURATIONPAGE FIGURE

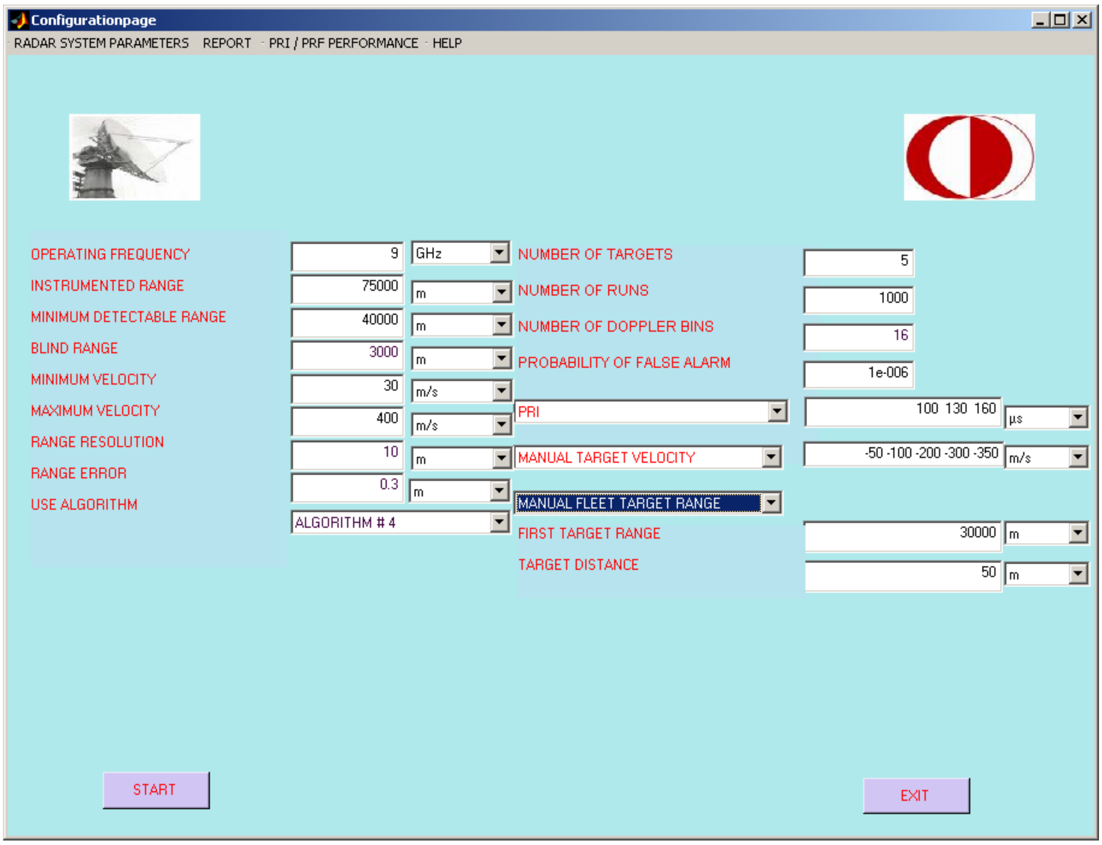


Figure 5 Configurationpage GUI

The configurationpage is the main figure of GUI . This is the opening window of software. It lets the user

- enter different system and test parameters so that the user can test the algorithms for different scenarios
- enter the operating frequency, instrumented range, minimum, maximum detectable ranges, blind range, range resolution, range error, number of Doppler bins, probability of false alarm values of the radar system
- enter the minimum, maximum velocities and number of targets
- enter either PRI or PRF for pulse repetition frequency.
- test the algorithms by entering the desired range and velocities of targets that are manually entered or enter the targets as a fleet by

entering the first targets position, number of targets and the distance of each fleet element

- test algorithms by using randomly created target values.
- select the desired algorithm from a popup menu. There are 3 algorithms in the menu that are previously loaded.
- enter the number of test runs.
- enter the units of parameters by popup menus

The system has many parameters and it is hard to enter them in every run again. The GUI stores the parameters of last run for preventing this and restores them .Opening the GUI restores them, so the user can test the algorithms by only modifying the parameters which may require modifications..

The GUI has a menu and some sub menus. RADAR SYSTEM PARAMETERS menu has a tab RESET SYSTEM PARAMETERS that clears all the edit boxes and an EXIT tab that closes the program.

Another menu is REPORT menu that has tabs OPEN REPORT, opens the saved reports and a PRINT REPORT menu that prints the report.

The other menu is PRI/PFR PERFORMANCE. This opens the PRI/PFR PERFORMANCE GUI that calculates and graphs the blind velocity, blind ranges of required PRF or PRI values and their ratios in the interested range of distance and velocity.

There is also a help tab that opens the help manual for the operation.

The edit boxes also have tool tip strings that help the user. They are displayed when the user locates the pointer of mouse on the edit boxes and waits.

There are also error dialogs that warn the user in case of a false data entry. For example if the minimum velocity is greater than maximum velocity it displays a bad input dialog with the warning message “MAXIMUM VELOCITY value should be greater than MINIMUM VELOCITY value”, or it may warn the user in case of a non numeric value entry to the edit boxes.

When all the inputs are correct the user can run the test by pressing the START button. After this the system calculates the statistics of algorithms and displays the REPORT with resultant graphs, calculations and system parameters that are applied. EXIT button closes the menu and saves the last entered values in a data structure that will be loaded as default system parameters for the next running of program.

3.1.2 THE GRAPHPAGE FIGURE

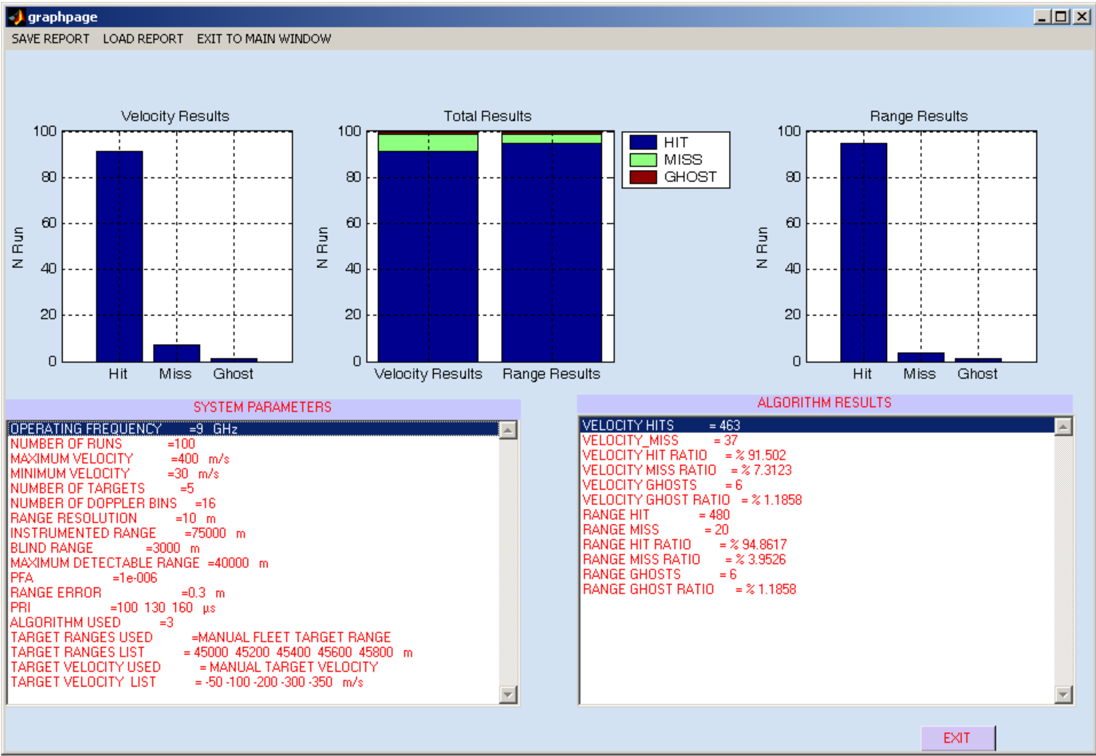


Figure 6 Graphpage GUI

THE GRAPHPAGE GUI is displayed after running the configurationpage by pressing the START button. The algorithm is run specified times by using the entered system parameters and the hit, miss, ghost results are graphed for velocity and range tests. The total hit, miss and ghost values of test for both range and velocity results are also displayed in another bar graph. The system parameters and the algorithm used in the test, target velocity and range values that are simulated are displayed in a list box so the user can examine the results with respect to the used parameters. It is also useful for the next studies in case of saving the report. The results of test are also displayed in another list box. The hit, miss and ghost percentages, number of hit, miss, ghost results and number of runs and targets are given as performance results. The GUI also has a REPORT menu that enables user to save the report by clicking the SAVE REPORT AS tab and to open an previously saved report by clicking the OPEN REPORT tab.

3.1.3 THE PRI_PRF_PERFORMANCE FIGURE

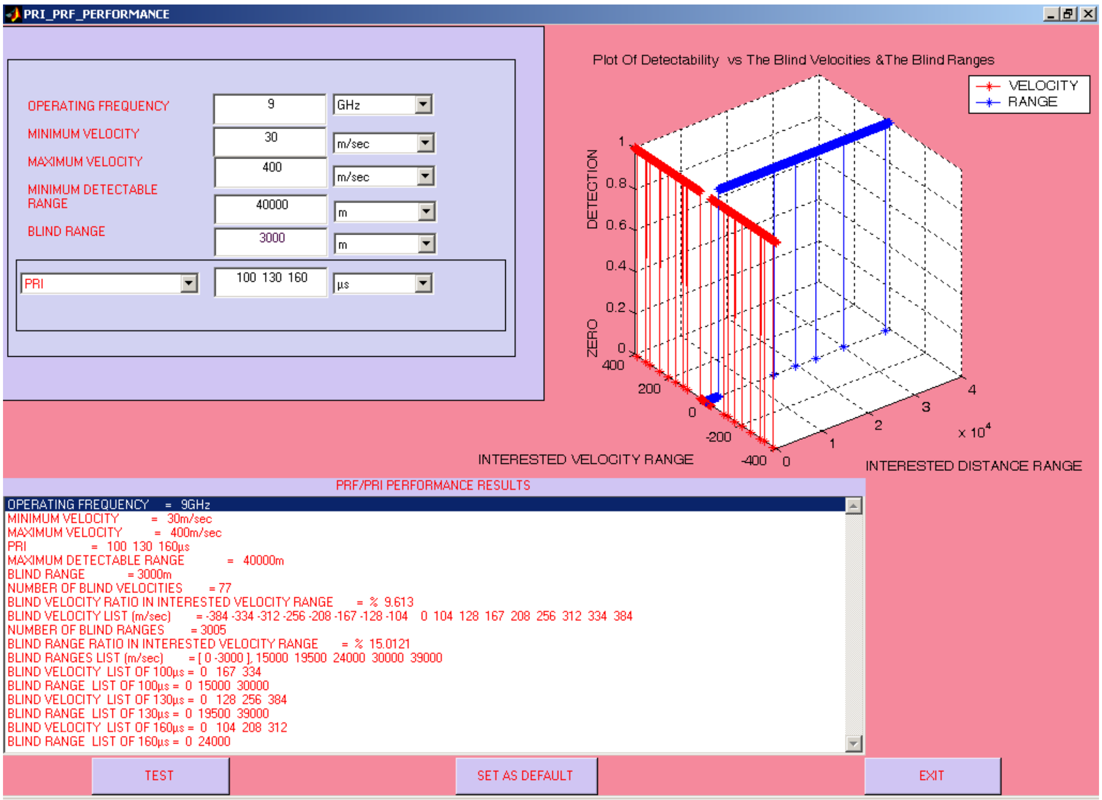


Figure 7 PRI/PRF Performance GUI

PRI_PRF_PERFORMANCE GUI is called by the configurationpage GUI menu. It uses the parameters of last run as default parameters. The aim of this GUI is to examine the blind range and blind velocity values for a given set or single PRI or PRF .Their ratios are also determined by using the maximum velocity, minimum velocity, maximum detectable range and minimum detectable range values and displayed in percentages. The blind values and zeros are displayed by a graph. This utility is useful for selecting a successful PRI set for the operation or examining the existing sets performance. The user also has the opportunity of testing the detectable ranges and detectable velocities for the required PRI set. The list of blind velocities and blind ranges are also displayed in the result report. There is a SET AS DEFAULT button that is used for using the last set values in the configuration page. Pressing this button sets the configuration pages PRI or PRF values, the maximum velocity, minimum velocity, maximum detectable range and minimum detectable range values to the studied values. EXIT button closes the GUI and switches to the main window.

3.2 THE SOFTWARE FUNCTIONS

The test program consists of GUIs, algorithms and functions.The test, statistics programs, sub programs and the algorithms are described below:

3.2.1 blindrange_list.m

function[len_blind_ranges,blind_ran_ratio,RB_List,result_ran,result_ran_list,r_blind]=blindrange_list(F0,pri,Rmax,Rmin)

This function returns the len_blind_ranges,blind_ran_ratio,RB_List, result_ran,result_ran_list,r_blind parameters by using F0,pri,Rmax,Rmin parameters. The aim of this code is to obtain the blind range list that is found by the relation that

$$R_{Blind} = \frac{c \times PRI}{2} \quad (6)$$

.The Blind range is repeated by each folding of the R_{Blind} till it reaches to the border value, Rmax. The blind ranges due to the blind zone of radar that is given by Rmin, minimum detectable range is also added later to this blind range list and their total average to the maximum detectable range Rmax is also calculated. This process is done for each PRI.

3.2.2 blindvelocity_list.m

function[len_blind_velocities,blind_vel_ratio,VB_List,result_vel,result_vel_list,
v_blindlist,v_blind]=blindvelocity_list(F0,pri,Vmax,Vmin)

This function finds the blind velocities for all PRIs in the PRI set .It also finds total blind velocity list of all PRIs and blind velocities ratio in the whole interested velocity interval. The function uses the relation to find the wavelength

$$\lambda = \frac{c}{F_0} \quad (7)$$

where c is the speed of light and F0 is the operating frequency of the radar system. Then find the blind velocity for the given PRI value by the formula

$$v_{blind} = \frac{\lambda \times PRF}{2} \quad (8)$$

and uses the script v_b(ii)=round(Lambda*prf(ii)/2). Then finds the maximum number of folding by the code VPFM=(floor(Vmax / v_b(ii))) for that PRI values blind velocity. Also the velocities values less than minimum detectable ranges are taken as zero. Then creates an array starts from 1 to till the maximum folding number VPFM and multiplies the array by the blind velocity to find the folded positive values. Than it flips the positive velocity array to find the decreasing array and changing the new arrays sign tu minus gives the negative folded values. Then concatenating the two array with 0 gives the total velocity list result in the interested velocity range that starts from the negative values till the maximum positive values. len_blind_velocities gives the number of blind velocities. blind_vel_ratio gives the ratio of blind velocities to the whole interested velocity ratio.

3.2.3 DopplerBinZ0.m

function y= DopplerBinZ0(Pri,F0,Ndop,Vtar)

This function find the Doppler bin number that corresponds to the target that has the velocity V_{tar} with respect to the used PRI value.The Doppler frequency is found by the relation

$$f_{dop} = \frac{2 \times v_{tar}}{\lambda} \text{. (9)}$$

The maximum detectable unambiguous velocity for the PRI value is given by

$$v_{unamb} = \frac{\lambda}{PRI} \text{.(10)}$$

The Doppler bin resolution is found by

$$D_{res} = \frac{PRF}{N_{dop}} \quad (11)$$

where Ndop is the number of Doppler bins. The Doppler bin number Dop is found for the positive velocities by the relation Dop=(floor((mod(VTAR,Vunamb)) *(Ndop/Vunamb)))+1 and for the negative Dop= (floor((mod(VTAR,Vunamb)) *(Ndop/Vunamb))). Adding 1 is for arranging the folding to the true bin number.

3.2.4 Find_Pd_Range.m

function PDM=Find_Pd_Range(Actual_Rt_bin,Rres);

This function calculates the probability of detection (PD) with respect to the distance of the target to the observation point. The actual target range is taken as range value for calculating actual PD values .The PD is given by the relation

$$PD = \frac{1}{2} - \Phi(k - \sqrt{2 \times SNR}) \quad (12)$$

Constant k is known as “margin”, and the threshold value is taken as k times RMS value of noise for detection and calculation of PD for a defined PFA.

The PD value of system for a target located at distance 45 km and a PFA value of 1e-6 is given as 0.95 by the scenario. The margin value k=4.75 . By using these values the SNR value for the target is given by the relation.

$$SNR = \frac{P_t G_t G_r \sigma \lambda^2 n L_n L_s}{(4\pi)^3 k T_0 F (B\tau)(PRF)} \cdot \frac{1}{R^4} \quad (13)$$

The left part of the equation except for range is named as A and its value as calculated taken as a coefficient. The ratio is varying inversely by the 4‘th power of range named as B, in meters. The bin numbers are multiplied by range resolution Rres for conversion to the meters unit. The SNR value is obtained by dividing A to the B and then this value is substituted in the equation (12) as PDM(aa)=1/2-(erf(((k-sqrt(2*SNR_Val))/sqrt(2)))/2) ; where PDM is the probability of detection matrix for the set of actual targets.[21]

3.2.5 search_HIT_V_F_MZ0

function[Velocity,merit,freq]=search_HIT_V_F_MZ0(searched_array,searched_hit,searched_merit,searched_hit_merit);

This function searches the unfolded hit value "searched_hit" in the unfolded velocity list named as searched_array and in case of occurrence it finds an average velocity with respect to their weighted merit average .At first step it checks the sign of searched hit. Then due to its sign it takes the positive or negative part of the searched array and the part of the searched hit merit that corresponds to these values .After this it subtracts the searched hit from searched hit array and its result gives the similar hits that are closer than error range interval and gives their indices. Then by using this list it calculates an merit weighted average velocity value and its total merit so it will be useful for determining more reliable values. Also it gives the number of occurrence of the searched hit by counting it and saves the result in the freq variable that means the frequency of occurrence.

3.2.6 search_HIT_R_F_MZ0

function[Range,merit,freq]=search_HIT_R_F_MZ0(searched_array,searched_hit,searched_merit,searched_hit_merit);

This function searches the unfolded hit value "searched_hit" in the unfolded range list named as searched_array and in case of occurrence it finds an average range with respect to their weighted merit average .At first step it subtracts the searched hit from searched hit array and its result gives the similar hits that are closer than error range interval and gives their indices. Then by using this list it calculates an merit weighted average range value and its total merit so it will be useful for determining more reliable values. Also it gives the number of occurrence of the searched hit by counting it and saves the result in the freq variable that means the frequency of occurrence.

3.2.7 searchV_MZ0.m

function [merit] = searchV_MZ0(searched_array,searched_hit)

This function searches the unfolded velocity hit value "searched_hit" in the unfolded velocity list named as searched_array and in case of occurrence it finds a merit .At first step it checks the sign of searched hit. Then due to its sign it takes the positive or negative part of the searched array .After this it subtracts the searched hit from searched hit array and its result gives the similar hits that are closer than error range interval and gives their indices. merit=merit+abs((error_range-abs(DetectionMatrix(ii)))) gives the merit of the hit. The closer hit gives the higher increment on merit by the calculation abs((error_range-abs(DetectionMatrix(ii)))) .Then it returns the merit value of velocity hit that will later help to decide the best hit estimation.

3.2.8 searchR_MZ0.m

function [merit] = searchR_MZ0(searched_array,searched_hit)

This function searches the unfolded range hit value "searched_hit" in the unfolded range list named as searched_array and in case of occurrence it finds a merit .At first step it subtracts the searched hit from searched hit array and its result gives the similar hits that are closer than error range interval and gives their indices.

merit=merit+abs((error_range-abs(DetectionMatrix(ii)))) gives the merit of the hit. The closer hit gives the higher increment on merit by the calculation abs((error_range-abs(DetectionMatrix(ii)))) .Then it returns the merit value of range hit that will later help to decide the best hit estimation.

3.2.9 searchV_M.m

function [merit] = searchV_M(NOFTARGETS,searched_array,searched_hit)

This function searches the unfolded range hit value “searched_hit” in the unfolded velocity list named as searched_array and in case of occurrence it finds a merit .At first step it checks the sign of searched hit. Then due to its sign it takes the positive or negative part of the searched array .After this it subtracts the searched hit from searched hit array and its result gives the similar hits that are closer than error range interval and gives their indices. merit=merit+abs((error_range-abs(DetectionMatrix(ii)))) gives the merit of the hit. The closer hit gives the higher increment on merit by the calculation abs(error_range-detectionMatrix(ii)) .Then it returns the merit value of range hit that will later help to decide the best hit estimation.

3.2.10 PRI_HIT_MIXING_ORDERING.m

function[HIT]=PRI_HIT_MIXING_ORDERING(pri,Vmax,Vmin,NOFTARGETS,Ndop,F0,Rres,Rinst,Actual_Rt_bin,Actual_Vtar);

In real operation the order of the targets in received signals is not in the same order for each PRI. Their order may be mixed. For simulating this, the order of the generated signals is randomly changed and their original order is obtained before starting the main algorithms. At first step the actual target ranges and velocities are transferred into range bins and Doppler bins due to the used PRIs. Then randomly number array with the size of the used PRIs range is generated and then these numbers are sorted. Their indexes are stored in another array. After sorting, the indexes are also sorted. The PRI hits are then sorted due to the indexes of the sorted random numbers. So randomly ordered hits are obtained. This procedure is applied to each PRI. All the range hits are unfolded with respect to the instrumented range. Then the unfolded values of each targets for first PRI are subtracted from the next PRIs unfolded target hits . If the difference of the searched hit is less then 5, then it is assumed to be matching and the merit for that hits is increased by 1. In each loop, the difference is checked and finally the merit array for the targets for the searched PRI is obtained. The element with the highest merit is considered to be matching signal for that PRI. There is an array named as

BOX that contains the numbers of targets. For example for 5 targets, BOX= [1,2,3,4,5] . If the result of the search is 3 then that target is eliminated from the array and BOX becomes as BOX= [1, 2,4,5] . The aim of this process is to decrease the detection steps and prevent reprocessing of detected hits. Also eliminating the detected ones is useful for decision in the further steps of undecided positions. The merit array can have more than one maximums. In this case it is not possible to decide which target this signal corresponds to. For example we may have detections like (1, 5) . So this multi result searches are stored in a new array. In case of detection, the detected target is eliminated from the targets array. Another position is having no detections. In this case the number of the detections is stored in an array that contains non detected ones. After the single detected ones are over, a new step for detection of multi results starts. Suppose that the remaining hits are [1,4]. The multi result detections are searched in the remaining possibilities. It is obvious that the hit for (1,5) corresponds to 1 in the remaining BOX elements. Then after eliminating 1, BOX=[4] . Then the step for non detected values begins. The no detected value corresponds to the remaining element,” 4”.In case of remaining more than one element, the selection is done randomly. The same procedure is applied to each PRIs signals and the relationship between PRI signals and targets orders is established.

3.2.11 TEST_PROGRAM.m

function[Velocity_Hit,Velocity_Miss,Velocity_HitRatio,Velocity_MissRatio,Range_Hit,Range_Miss,Range_HitRatio,Range_MissRatio,Range_Ghost,Range_GhostRatio,Velocity_Ghost,Velocity_GhostRatio,VEL,RAN,RES]=TEST_PROGRAM(NRun,Vmax,Vmin,NOFTARGETS,Ndop,F0,Rres,Rinst,Rmin,Rmax,Pfa,Re,algorithym,popupmenu,prf,Vtar,Rtar,pri,FFTAR,FTARDIST);

This function is called by pressing the START button in the configurationpage GUI. It uses the NRun,Vmax,Vmin,NOFTARGETS,Ndop,F0,Rres,Rinst,Rmin,Rmax,Pfa,Re,prf,Vtar,Rtar,pri,FFTAR,FTARDIST values that are entered by the user and the algorithm to be used by the variable algorithm and stores the coefficients of multiplies for the user selected units in the structure named as popupmenu

.By using these values it multiplies the variables with their coefficients and decides PRI or PRF values to be used and the target data creation so the user can select random, fleet or user defined target range and velocity values to be used in the test of algorithm. After creating all the data set it calls the function statistics.m that runs and does the statistics of the algorithms. Then the statistics gives us the data set of the algorithm test,
Velocity_Hit,Velocity_Miss,Velocity_HitRatioVelocity_MissRatio,Range_Hit,Range_Miss,Range_HitRatio,Range_MissRatio,Range_Ghost,Range_GhostRatio,Velocity_Ghost,Velocity_GhostRatio.

The velocity results for the final graphing is calculated as:

VEL=[Velocity_HitRatio*NRun,Velocity_MissRatio*NRun,Velocity_GhostRatio*NRun]

And the range results are calculated as:

RAN=[Range_HitRatio*NRun,Range_MissRatio*NRun,Range_GhostRatio*NRun]

And the total result is the combination of range and velocity given by:

RES=[VEL;RAN] for using in plotting of results.

3.2.12 Statistics.m

function [Velocity_Hit,Velocity_Miss,Velocity_HitRatio,Velocity_MissRatio, Range_Hit,Range_Miss,Range_HitRatio,Range_MissRatio,Range_Ghost,Range_GhostRatio,Velocity_Ghost,Velocity_GhostRatio]=statistics(NRun,pri,Vmax,Vmin,NOFTARGETS,
Ndop,ErrorRangeV,ErrorRangeR,F0,ZeroDopBin,Rres,Rinst,Nblind,Rmin,Rmax,Pfa,Re,algorithym,popupmenu,Vtar,Rtar,FFTAR,FTARDIST);

This function is called by the TEST_PROGRAM.m and it runs one of the algorithms that the user selected and its value is stored in the variable, named as algorithm. It runs the selected algorithm for the user defined test number, NRun times and for each run it compares the algorithm results with the actual target values that are created for that run and they are returned by the running algorithm. The algorithm may return results more than the number of actual targets. This may be caused by the occurrence of ghost targets. From the first result till the last result It takes the difference of the velocity and the range detections of the run and actual values. If the result is smaller than the error range than it adds one to the hit values, else it increases the miss result values. If one of the results is found in the actual list, it is removed from the actual list. This elimination decreases number of actual hits to be compared and provides less calculation steps. There may be more than one close result and if the elimination is not done, all may be found as successful results. For these reasons after all comparison, the found hit is removed from the actual list. If the hits and miss total is more than the actual target number then the other hits are defined as ghost values. After each running of the selected algorithm, their hit, miss and ghost values for range and velocity results are added on the previous runs results and their final values are called and assigned as the variables:

Velocity_Hit,Velocity_Miss,Velocity_HitRatio,Velocity_MissRatio,

Range_Hit,Range_Miss,Range_HitRatio,Range_MissRatio,Range_Ghost,Range_GhostRatio,Velocity_Ghost,Velocity_GhostRatio where hit means a successful result, miss means a false result and ghost means a non existing target in the test for the velocity and range estimations. The results are divided by the number of runs times the number of targets, and their ratios are found as of percentages.

3.3 THE OPERATION MECHANISM OF SOFTWARE:

3.3.1 THE USER INTERFACES OPERATIONS

The aim of this software is testing the performances of the developed algorithms by using both the required system parameters and by altering the system parameters and observing their effects on the algorithm performances. For this reason a Matlab GUI is designed for allowing the user entering the parameters and observing the results. The software has three windows:

1. Configuration Page
2. Result Page
3. PRI/PRF Performance Page

The Configuration page is the main window of the GUI. It allows user to enter the system test parameters. Once the parameters are tested, it stores the parameters and the parameters are reloaded in the next sessions.So the user do not need to enter all the parameters for each test.

The parameters are stored in a data file named as “lastconguration.dat”. It stores the datas in a file named “configuration”.The datas are stored by the pressing START and EXIT button events. A sample of stored data is given below:

lastconguration.dat

configuration =

VEL: 0

RAN: 0

RES: 0

algorithym: 3

popupmenu: [1x17 double]

popupmenucontents1: 'GHz'

popupmenucontents2: 'm'

popupmenucontents3: 'Km'

popupmenucontents4: 'Km'

popupmenucontents5: 'Km/h'

popupmenucontents6: 'Km/h'

popupmenucontents7: 'm'

popupmenucontents8: 'm'

popupmenucontents9: 'μs'

popupmenucontents10: 'MHz'

popupmenucontents11: [1x62 char]

popupmenucontents12: [1x28 char]

popupmenucontents13: [1x22 char]

popupmenucontents14: 'm'

popupmenucontents15: 'm/s'

popupmenucontents16: 'm'

popupmenucontents17: 'm'

NRun: 10

Vmax: 400

Vmin: 30

NOFTARGETS: 3

Ndop: 16

F0: 9

Rres: 10

Rinst: 75000

Rmin: 3000

Rmax: 50000

Pfa: 1.0000e-006

Re: 0.3000

pri: [100 130 160]

prf: [10 13 16]

Rtar: [1x3 double]

Vtar: [700 280 290]

FFTAR: 8000

FTARDIST: 60

The program has radar system parameter entries as:

Pulse Repetition Intervals /Pulse Repetition Frequencies
Instrumented Range
Minimum Detectable (Blind Region) Range
Maximum Detectable Range
Length of Resolution Cell
Range Error
Maximum - Or + Speed of Targets Observed
Minimum - Or + Speed of Targets Observed
Operating Frequency
The Doppler Bin Number for Each PRI
Probability of False Alarm
Probability of Detection= 0.95
Zero Doppler Bin

The units of the entries can also be altered and through the calculation process, they are multiplied with the units' coefficients.

The input boxes also have tool tips. They are displayed when the pointer of the mouse enters and waits in the edit box. This helps the user to enter true units and inputs.

The program also contains some error dialog warning messages in case of a false entry. For example if Vmax is less than Vmin or minimum detectable range is greater than the instrumented range or the manual velocity entrance is different then the number of targets entered, it warns the user by displaying an error dialog box.

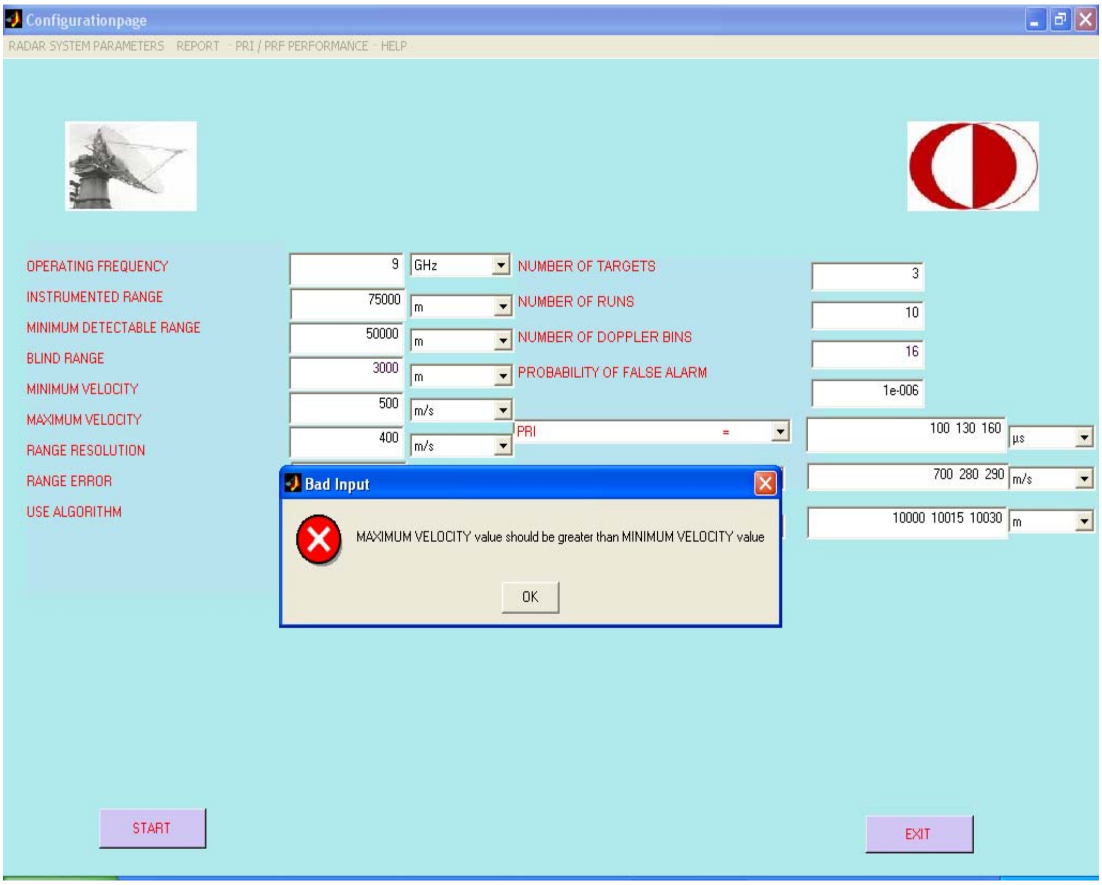


Figure 8 Error Dialog Boxes and Warnings

The steps after the data entry are as fallows:
Configuration page calls the test program
Test program calls the statistics program
Statistics calls the selected algorithm number of runs times
Statistics calculates and sends the results to the test program
Test program calls the result page and displays the results.

After pressing the start button the datas are stored in the configuration file.The software calls the test program with the following command line:

[Velocity_Hit,Velocity_Miss,Velocity_HitRatio,Velocity_MissRatio,Range_Hit, Range_Miss,Range_HitRatio,Range_MissRatio,Range_Ghost,Range_Ghost Ratio,Velocity_Ghost,Velocity_GhostRatio,VEL,RAN,RES]=TEST_PROGRA M(handles.config.NRun,handles.config.Vmax,handles.config.Vmin,handles.c onfig.NOFTARGETS,handles.config.Ndop,handles.config.F0,handles.config.Rres,handles.config.Rinst,handles.config.Rmin,handles.config.Rmax,handles.config.Pfa,handles.config.Re,handles.config.algorithym,handles.config.popupmenu,handles.config.prf,handles.config.Vtar,handles.config.Rtar,handles.config.pri,handles.config.FFTAR,handles.config.FTARDIST);

In addition to the parameter values the inputs of the function also includes the coefficients of the units with the array popupmenu. The popupmenu variable is an array that consists of the selected indexes of the popup menus that are defined previously. Later it returns the ghost, hit, miss values their ratios for the velocity and the range results.

The test program multiplies the input parameters with their coefficients due to their selected units. The units are read from the array popupmenu. The popup menu is a [1x17] array. It contains the index of the selected popup menu element. The text value of the selections are stored in the variables "popupmenucontents " that has the same dimension with the popupmenu .For example if maximum detectable range is entered in Km units, popupmenu(3) will be equal to 2 and popupmenucontets3 will be equal to "Km".A sample of its content is given below:

popupmenu: [1x17 double]
popupmenucontents1: 'GHz'
popupmenucontents2: 'm'
popupmenucontents3: 'Km'
popupmenucontents4: 'Km'
popupmenucontents5: 'Km/h'
popupmenucontents6: 'Km/h'
popupmenucontents7: 'm'
popupmenucontents8: 'm'
popupmenucontents9: 'µs'
popupmenucontents10: 'MHz'
popupmenucontents11: [1x62 char]
popupmenucontents12: [1x28 char]

popupmenucontents13: [1x22 char]
popupmenucontents14: 'm'
popupmenucontents15: 'm/s'
popupmenucontents16: 'm'
popupmenucontents17: 'm'

The popupmenu and popupmenucontents also contain the values of selection of PRI or PRF, selection of random or manual target velocity, selection of random, fleet or manually entered target ranges menus.
These values are also used in reporting for showing the inputs of the test.

After this it calls the statistics.m function and uses its outputs for creating the report graphics.
The test program calls the statistics function by the command:

[Velocity_Hit,Velocity_Miss,Velocity_HitRatio,Velocity_MissRatio,Range_Hit,Range_Miss,Range_HitRatio,Range_MissRatio,Range_Ghost,Range_GhostRatio,Velocity_Ghost,Velocity_GhostRatio]=statistics(NRun,pri,Vmax,Vmin,NOFTARGETS,Ndop,ErrorRangeV,ErrorRangeR,F0,ZeroDopBin,Rres,Rinst,Nblind,Rmin,Rmax,Pfa,Re,algorithym,popupmenu,Vtar,Rtar,FFTAR,FTARDIST)

It calls the algorithm that is defined by the variable “algorithm” .After this it runs the selected algorithm for number of runs times. In each run it takes the results of velocity and range values and searches them in the actual target values that are created in the beginning of the algorithm block with respect to the radar parameters. The number of returned results may exceed the previously defined target number because of false alarms. Such targets are defined as ghosts. There are tree algorithms to be tested. Some additional algorithms can also easily be added since the target creation and testings are the same, only defining the calculation methods will satisfy the performance system of new algorithms. The present algorithms are as:
ClusterSearchSoftwareVRAGD16_1
ClusterSearchSoftwareVRAGD16_2
ClusterSearchSoftwareVRAGD16_3

ClusterSearchSoftwareVRAGD16_4

Each algorithm has different methods for calculations. The statistics call the desired algorithm. All the algorithm functions have the same input and output parametersThe first algorithm is called by the command :
[Actual_Rt_bin,Actual_Vtar,TAR]=ClusterSearchSoftwareVRAGD16_1(pri,Vmax,Vmin,NOFTARGETS,Ndop,F0,ZeroDopBin,Rres,Rinst,Nblind,Rmin,Rmax,Pfa,Re,popupmenu,Vtar,Rtar,FFTAR,FTARDIST)

3.3.2 DATA CREATION FOR ALGORITHMS

The first step in the algorithms is preparing the target velocities and ranges with respect to the user inputs and system parameters and this is a common procedure of data generation for all algorithms. If the user selects random velocity, it creates a random velocity array with the size equal to the number of targets that have the value between –Vmax and +Vmax. If the user enters predefined velocity values, hay are assigned as the actual velocity values. For the range the input selecting is examined again. If the user selects random range, a random array is created with the size equal to the number of targets and has the values between 0 and instrumented range. If the user selects fleet values, it takes the fist fleets range and adds new target behind it by every fleet distance till it reaches to the defined number of targets .If manual target entry is selected, the array is created by the inputs of the user .The number of the inputs and the number of targets entered are compared and in case of a mismatch, it warns the user in the configurationpage process. Once the actual datas are created, they are stored for comparing the algorithm results.

The range values are divided by the length of range bins and they are converted to the range bin numbers .After this the PRI bins are found so that they repeat the signal by every PRI bin number and the received signal is folded by this PRI number. For each PRI the range bin numbers are divided by the corresponding PRI bin number and their remainder gives us the folded value of received signal, as it happens in the radar range operation. The velocity values are also converted to Doppler bins by the function DopplerBinZ0.m. Converting the velocities into the Doppler bins is also a simulation for the radar receivers.

The next step is applying probability of detection (PD) . Each targets probability of detection is calculated by the function Find_Pd_Range.m with respect to their ranges. The calculation is based on the given requirement as PD=0.95 for target located at 45 Km. After calculating each targets PD, a new array of random numbers having values between 0 and 1 and has the length equal to the number of targets is created. This is for creating random and statistical detections. Then the calculated PD and the random PD are compared. If the random PD is greater than the calculated, that target is assumed to be not observed and its index in the target is recorded as miss index, else it is defined as detected and its index is recorded as detection index. The miss index valued targets observed values are set to 0 that expresses the zero detection.

The following operation is detecting the ranges that are corresponding to the blind zone. As the real radars is unable to see the targets in the blind range zone, we have to apply blind zone effect to the detection values. The range values less then the blind zone are defined as miss index and the targets located further than the blind zone defined as the detection index again. Observed doppler is set to zero for targets with a miss index.

In real operation the Doppler values in the Zero Doppler bin are not calculated and these are the vested datas. The Doppler values of the targets whose Doppler bins are corresponding to the zero Doppler bin are also defined as the miss, so their indexes are defined as miss index and the others are called as detection index. The miss index valued targets observed Doppler are also set to 0.

Another effect on received signal is probability of false alarms (Pfa). The system repeated for each PRI, because Pfa may be observed I each PRI value independently. For applying this, a two dimensional array with Doppler and range bin dimensions is created. The blind zone and the zero Doppler bins are omitted. Random numbers are also created ad compared with the given Pfa level. If the number is less than Pfa, it is assumed as we received a signal from that point as Doppler and range. The results are called as false targets.

The false target range bins and Doppler bins are added to the actual target arrays including the PRI value that they are observed. Because the unfolding will be done by using these observed PRI values. A final target is created that includes actual targets and false targets. The algorithm is applied to this new array and the processes will be repeated for the every target.

For algorithm 1, 2, 3 the received signals are first mixed, then the signals of each target in each PRI are determined and sorted. So the processes are done for only each target, not all of the target signals together at the same time. This provides simplicity in steps and prevents data conflicts.

In the algorithm 4, there is not such an ordering step. All the unfolded values of targets for a PRI are searched in the other PRIs unfolded values.

The target preparation is the same for all the algorithms.

3.4 ALGORITHMS

3.4.1 ALGORITHM 1

The algorithm 1 starts with range calculation. First the range bins are unfolded. The maximum unfolding number is calculated for preventing the calculation of unfolded values that exceeds the range that is interested. The range values are unfolded by this number. Unfolding is done by adding the n times PRI bins to the folded range bin where n is from 0 to maximum folding value. All the values of a target is unfolded for each PRI. For algorithm 1, we take the unfolded values of PRI 3 and search the each value in unfolded values of PRI 1 . The value of PRI 3 is called the searched hit and the set of PRI 2 is called the searched array. The searched is seeked in the searched array and its like hood is evaluated by a merit value and this is done by the function search_M.m. The same procedure is repeated for PRI 3 and PRI 2. After this the merit results for the searched hit are added. The hit with maximum merit selected as the hit. If there are more than one hit having maximum merit we select one of then randomly, a small array with the size of maximum merits number is created and filled with random numbers. The greatest numbered elements index is selected as the hit and range value corresponding to that merit is assigned as target hit.

The algorithm goes on by the velocity calculations.. First all the folded velocity values are unfolded. Unfolding is done by using the used PRI values. The unfolding process is done by using the function VELOCITY_UNFOLDZ0.m and it returns the unfolded velocity array for the given Doppler bin. The operation is repeated for each target and each PRI. After this a two dimensioned array consisting the pair combinations of PRI numbers is created. For example if we operate with 3 PRIs, the combinations will be as [(1,2),(1,3),(2,1),(2,3),(3,1),(3,2)].Then the searching process is done for each of these pairs. The first element is used for searched array and the second element is used for the searched hit. For example if the pair is (1,3), the searched array is the unfolded velocity list of PRI 3 and the searched hit is an unfolded velocity element of PRI 1.Each element of PRI 1 is searched in the whole array of PRI3. The searching is done by using the function searchV_MZ0.m and it returns the merit values of the searched hit. If the merit is nonzero, then it is assigned as the merit of that hit. If not, it is ignored for preventing useless calculation works. The same procedure is applied to all of the combination pairs.

The hits having merits are sorted and the merits are also sorted. Then the hits are searched again for finding the closest ones among them, a like hood detection is done. Each hit is searched in the targets hit array and its frequency of occurrence is calculated. The searched hits velocity is checked at first. If it is negative, only the negative part of the searched hit is examined, else the positive part of the array is examined. The merits of the close hits are added and the number of the close hits are counted and loaded into a variable named “frequency”. After this an average of close hits is calculated. All these steps are done by the function search_HIT_V_F_MZ0.m .In the next step each sorted new velocities with their new merits are compared with their consecutive hits. If their absolute difference is less than 3, their merits are added and their average is assigned as the hits of the target. The number 3 is selected as a decision level because the greatest velocity difference between consecutive bins is about 6 m/sec . So an absolute difference of -3 and +3 is about 6, where it corresponds to the maximum velocity difference of bins.

Finally the index of the hits with the highest merits is selected. There may be more than one hit having the same highest merit value with different velocities. For preventing returning of multi result the length of the detection is checked. If there is one result, the index of the hit with that index is assigned as the final hit value, else one of the indexes is selected and the hit with that index assigned as the final hit value. If the examination gives no valid merit result, then one of the hit among the last hit array is selected randomly and assigned as the final hit value.

3.4.2 ALGORITHM 2

The data creation step of algorithm 2 is the same as algorithm 1.

Algorithm 2 also begins range calculations.. First the range bins are unfolded due to the maximum unfolding number. Unfolding is done by adding the n times PRI bins to the folded range bin where n is from 0 to maximum folding value. All the values of a target is unfolded for each PRI. For algorithm 1, we take the unfolded values of PRI 3 and search the each value in unfolded values of PRI 1 . The value of PRI 3 is called the searched hit and the set of PRI 2 is called the searched array. The searched is seeked in the searched array and its like hood is evaluated by a merit value and this is done by the function search_M.m. The same procedure is repeated for PRI 3 and PRI 2. After this the merit results for the searched hit are added. The hit with maximum merit selected as the hit. If there are more than one hit having maximum merit we select one of then randomly, a small array with the size of maximum merits number is created and filled with random numbers. The greatest numbered elements index is selected as the hit and range value corresponding to that merit is assigned as target hit.

The second step is target velocity calculation. First all the folded values are unfolded. Unfolding is done by using the used PRI values. The unfolding process is done by using the function VELOCITY_UNFOLDZ0.m and it returns the unfolded velocity array for the given Doppler bin .After unfolding an array is created with values +2Vmax and -2Vmax where that values represent border limitations of velocity. For each PRI, the unfolded values are added to the array and sorted. So we evaluate series of velocities from -+2Vmax to -2Vmax. Then starting from the first element, we subtract the each ii'th element from the successive ii+1'th element and create a new array consist of their absolute difference. The new array is examined and the index of differences which are less than 3 or equal to 0 found. If there is no difference proving this criteria, the final velocity is assigned as "0". If there one index, the elements resulting that indexed difference are added and their average is taken. The average is assigned as the final hit. If there are more than one index one of them is randomly selected. The selection is done by creating a random array with the same size of the found indexes .The one that is the greatest is selected and its order is found. From the index array, the element with that index is assigned as the index of the result and the hits that result that indexed differences are taken. Their average is assigned as the final hit result.

3.4.3 ALGORITHM 3

The data creation step of algorithm 3 is the same as algorithm 1.

The range calculations are done at first step.. First the range bins are unfolded due to Used PRI values.The unambiguous range values of each PRI is unfolded by its maximum unfolding number. Unfolding is done by adding the n times PRI bins to the folded range bin where n is from 0 to maximum folding value. All the values of a target is unfolded for each PRI.

After this step each targets unfolded range array of the used PRI are concatenated with [0,(Rinst+10000)] array and sorted. Then the targets unambiguous range array for the used PRI becomes [0, unfolded range values of target for used PRI, (Rinst+10000)] . A new array of difference is created by subtracting each ii'th element from the (ii+1) element of this array. The differences less then 3 are detected and their indexes are stored in a temporary array. The unfolded elements with these indexes are the close hits. These hits are the possible hit values and they are taken into a new array.

The other step is again creating an array by concatenating these values with [0,(Rinst+10000)]. Then, a new array of difference is created by subtracting each ii'th element from the (ii+1) element of this array. The differences less then 3 are detected and their indexes are stored in a temporary array. The possible hits with these detected indexes are called as a hit and assigned as a final range hit for that target.

The algorithm may rarely return none or sometimes more than one final hit for a target. The number of final detection is checked by using the length of detection indexes. If length is equal to zero, it means there is no decision. In this case, one of the possible hits is selected randomly. If length is equal to 1, it means there is one detection and there is no problem about the result. If length is more than one, it means there is more then one detection. In this case one of the final hits is selected randomly.

Algorithm 3 goes on by velocity calculations. First all the folded values are unfolded. Unfolding is done by using the used PRI values. The unfolding process is done by using the function VELOCITY_UNFOLDZ0.m and it returns the unfolded velocity array for the given Doppler bin .After unfolding an array is created with values +2Vmax and -2Vmax where that values represent border limitations of velocity. For each PRI, the unfolded values are added to the array and sorted. So we evaluate series of velocities from -2Vmax to +2Vmax.

After this step each targets unfolded velocity array of the used PRI are concatenated with [0,(Rinst+10000)] array and sorted. Then the targets unambiguous velocity array for the used PRI becomes [-2Vmax, unfolded velocity values of target for used PRI, +2Vmax] . A new array of difference is created by subtracting each ii'th element from the (ii+1) element of this array. The differences less then 3 are detected and their indexes are stored in a temporary array. The unfolded elements with these indexes are the close hits. These hits are the possible hit values and they are taken into a new array.

A new array is created by concatenating these values with [-2Vmax, +2Vmax]. Then, a new array of difference is created by subtracting each ii'th element from the (ii+1) element of this array. The differences less then 3 are detected and their indexes are stored in a temporary array. The possible hits with these detected indexes are called as a hit and assigned as a final velocity hit for that target.

The algorithm may rarely return none or sometimes more than one final hit for a target. The number of final detection is checked by using the length of detection indexes. If length is equal to zero, it means there is no decision. In this case, one of the possible hits is selected randomly. If length is equal to 1, it means there is one detection and there is no problem about the result. If length is more than one, it means there is more then one detection. In this case one of the final hits is selected randomly.

3.4.4 ALGORITHM 4

The data creation step of algorithm 4 is the same as algorithm 1. But in this algorithms, the input signals are not sorted. Each element is searched in each unfolded PRI values set.

In this algorithm, first the range bins are unfolded. The maximum unfolding number is calculated for preventing the calculation of unfolded values that exceeds the range that is interested. The unambiguous range values of each PRI is unfolded by its maximum unfolding number. Unfolding is done by adding the n times PRI bins to the folded range bin where n is from 0 to maximum folding value. All the values of a target are unfolded for each PRI.

The unfolded ranges of all detected targets for each PRI is concatenated and they are called as GROUP and number of used PRI times GROUPs are created.

After this, the two element combinations for the number of PRI are created and the procedure is repeated for every pair. Suppose that a combination pair is (a, b). Every unambiguous range element of the PRI b are searched in the GROUP that corresponds to the PRI a . this is done for every combination, so that every element is searched in every GROUP. The merit of each hit is calculated by the function searchR_MZ0.m . If a searched hits merit in a GROUP is greater than zero, then it is evaluated as a hit and it is added to that targets possible hits.

Every possible hit is searched in the possible hits set of the target by the function search_HIT_R_F_MZ0 and their merits are calculated.
The possible hits and their merits of the each target are sorted .Then the each possible hit is searched in the possible hit set of the target and the close hits merits are added. In the end, every hit gets a total merit and if there are other close hits to the searched hit, its merit gets higher.

In the next step, the length of possible hits is found and from the first one to the last one, each possible new detections of a target is subtracted from the next element. If their difference is less then 5, then their merit is added and the hits average is taken. If it is greater then 5, then it remains unchanged.

Finally the hit with the highest merit is assigned as the final range hit of that target. If there are more than one different hit with equal highest merit, then one of them is assigned as final hit. If there is not such a hit, one of the possible hits is assigned randomly. This occurs rarely but it is sufficient for preventing running error of software.

For the velocity calculations, first all the folded values are unfolded. Unfolding is done by using the used PRI values. The unfolding process is done by using the function VELOCITY_UNFOLDZ0.m and it returns the unfolded velocity array for the given Doppler bin

The unfolded velocities of all detected targets for each PRI is concatenated and they are called as GROUP and number of used PRI times GROUPs are created.

Then the two element combinations for the number of PRI are created and the procedure is repeated for every pair. Suppose that a combination pair is (a, b). Every unambiguous velocity element of the PRI b are searched

in the GROUP that corresponds to the PRI a. This is done for every combination, so that every element is searched in every GROUP. The merit of each hit is calculated by the function searchV_MZ0.m . If a searched hits merit in a GROUP is greater than zero, then it is evaluated as a hit and it is added to that targets possible hits.
Every possible hit is searched in the possible hits set of the target by the function search_HIT_V_F_MZ0 and their merits are calculated.

The possible hits and their merits of the each target are sorted .Then the each possible hit is searched in the possible hit set of the target and the close hits merits are added. In the end, every hit gets a total merit and if there are other close hits to the searched hit, its merit gets higher.

In the next step, the length of possible hits is found and from the first one to the last one, each possible new detections of a target is subtracted from the next element. If their difference is less then 5, then their merit is added and the hits average is taken. If it is greater then 5, then it remains unchanged.

Finally the hit with the highest merit is assigned as the final velocity hit of that target. If there are more than one different hit with equal highest merit, then one of them is assigned as final hit. If there is not such a hit, one of the possible hits is assigned randomly. This occurs rarely but it is sufficient for preventing running error of software.

CHAPTER 4

4. THE SOFTWARE TESTS AND RESULTS

The software is tested for different parameters and their effects on performances of the algorithms are observed. The parameters remained constant in the tests due to the scenario, except the studied test parameter. The tested parameters are the instrumented range of the radar, minimum detectable range, maximum detectable range, length of the resolution cell, maximum speed of observed targets minimum speed of observed targets, operating frequency of radar, Doppler bin numbers, probability of false alarm (Pfa), number of runs for the stability of results, positive and negative different manually entered target velocities, manually entered target ranges, manually entered fleet target ranges for different distances between targets, random target ranges and velocities and different number of PRI s .The whole tests are done by using 5 targets.

4.1 THE NUMERICAL TESTS OF ALGORITHMS

The algorithms are first created for no loss conditions. In the performance tests, all the given parameters are applied and they caused data lost in processes. For example, if a target is located at far distance, its probability of detection becomes very small and the received data will be taken as zero. The other fact is probability of false alarms. In case of false alarms, the signals can be confused and it may cause false decisions. Also another fact causing data lost is minimum detectable range. If a target is located in the minimum detectable range, its data set will also be detected as zero. The next effect is minimum detectable velocity. If a targets velocity is below this value, its velocity will also be accepted as zero. If a targets value corresponds to zero Doppler bin, the signal will be also zero. For preventing these looses some of the parameters are changed. The targets are created at instrumented range =40 km for probability of detection lost. The probability of false alarm level is set to 1e-9, almost no false alarms. The minimum detectable range is set to 0 m and minimum detectable velocity is set to 0 m/sec .The tests are done for 1000 runs, for evaluating stable results. The numerical test results for the algorithms are given below:

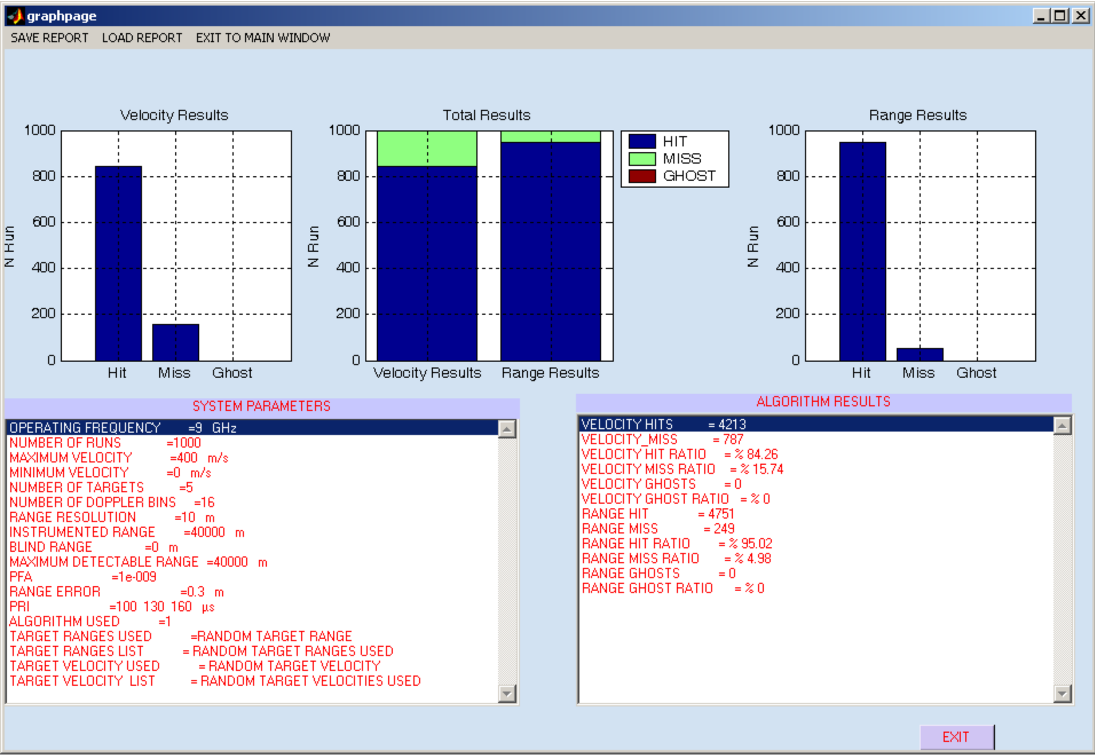


Figure 9 Numerical Test Results Of Algorithm 1

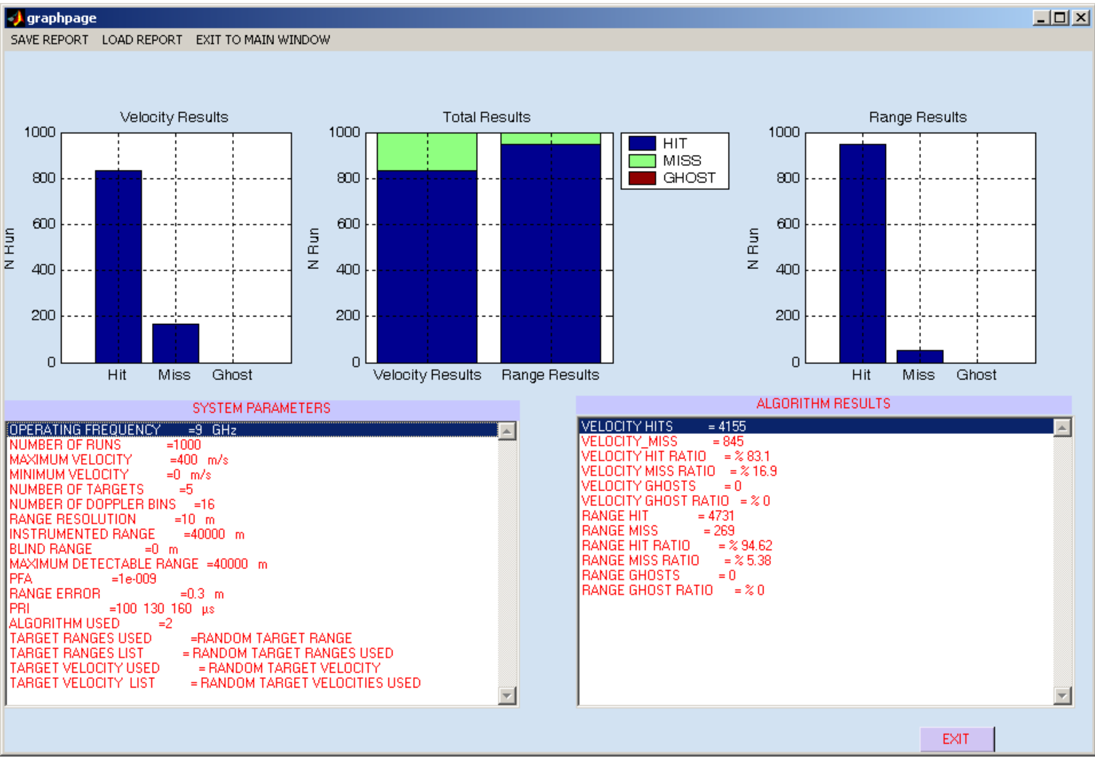


Figure 10 Numerical Test Results Of Algorithm 2

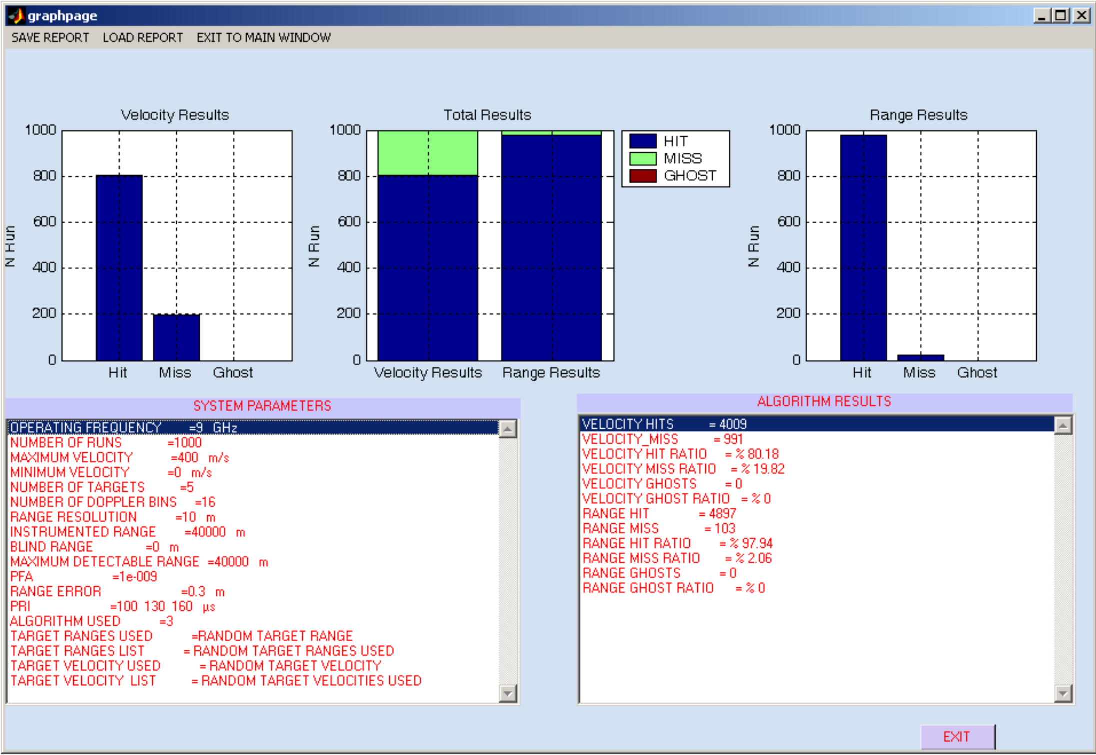


Figure 11 Numerical Test Results Of Algorithm 3

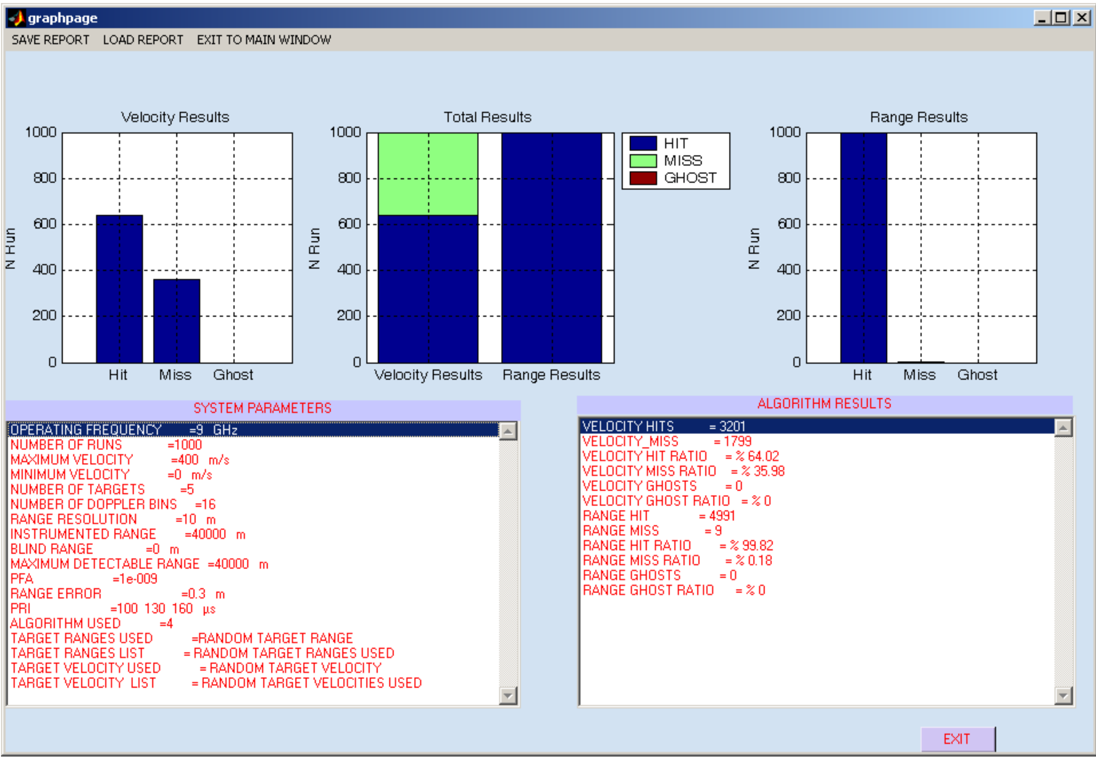


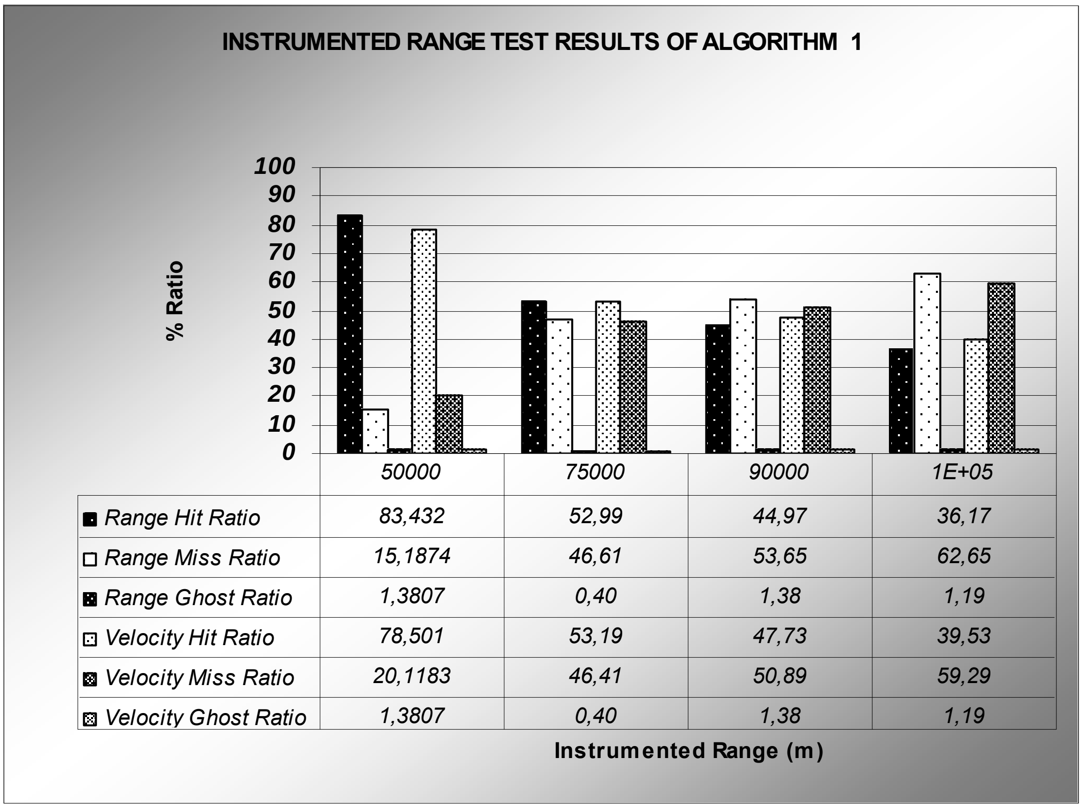
Figure 12 Numerical Test Results Of Algorithm 4

From the results,it is seen that the algorithm 4 is superior than all of the algorithms in range detection. But it has a poor performance in velocity detection. Algorithm 1 and algorithm 2 has almost the same performance .

However they have good performance in velocity detection, they are not as good as algorithm 3 and 4 in range detections. Among the all algorithms, algorithm 3 seems to be the optimum solution for resolving range and Doppler problem. From the results, all the algorithms have more than 80 % success in velocity and about more than 95% success in range calculations. But if they are tested by taking into account of false alarms, blind zone, minimum detectable velocity, probability of detection, their performance decrease due to the entered parameter levels. Most of the data are ignored by the test program because of data loss due to these parameters and the remaining data are send to the algorithms as input. The test results will not represent the actual success of algorithms . They will only help to understand the effects of the radar parameters on detection performance.

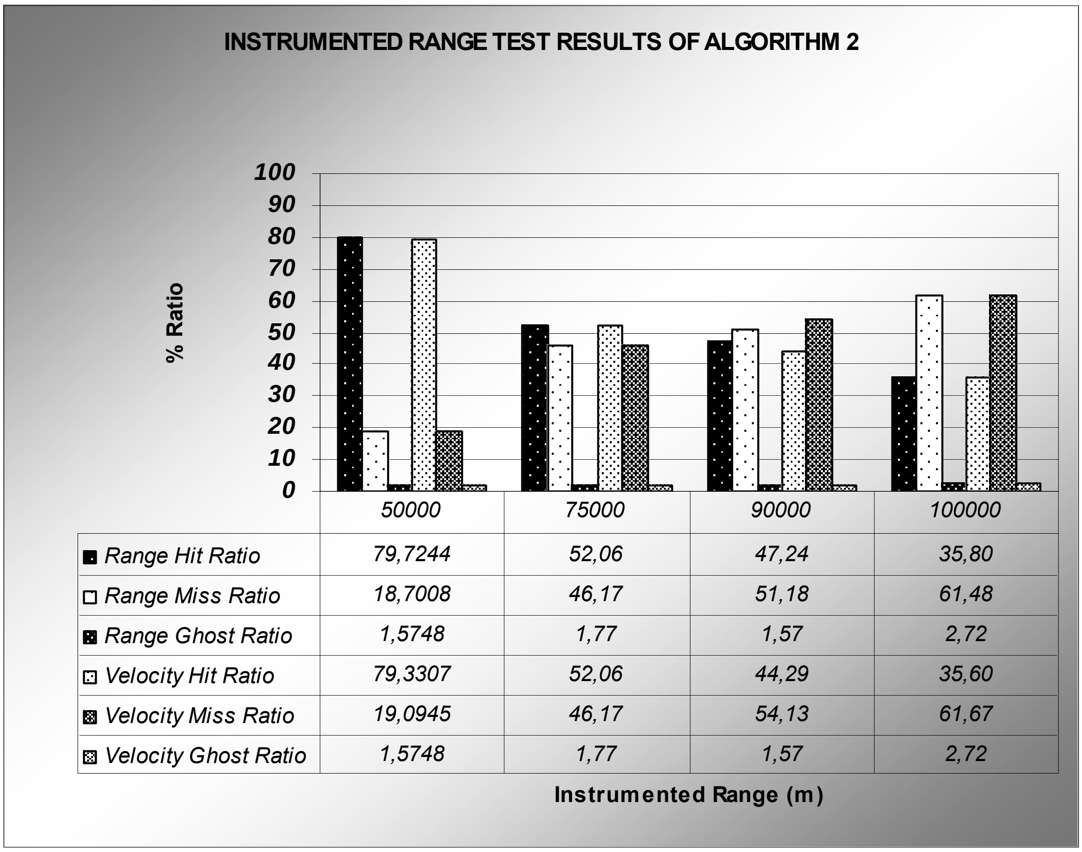
4.2 THE INSTRUMENTED RANGE TESTS:

The instrumented range of the radar is tested for the ranges 50.000 m, 75.000 m, 90.000 m and 100.000 m. As the instrumented range is increased, the targets can be located further than the maximum detectable range and their probability of detection will be decreased. The SNR varies by range as $(Range)^{-4}$. So the fraction of randomly created targets can be located far away will be large and their detection probability will be small. This will cause failure in detections. For this reason, as the difference between minimum detectable range and instrumented range gets larger, the performance of the algorithms will be reduced. The test results of algorithms for different instrumented ranges are given below:



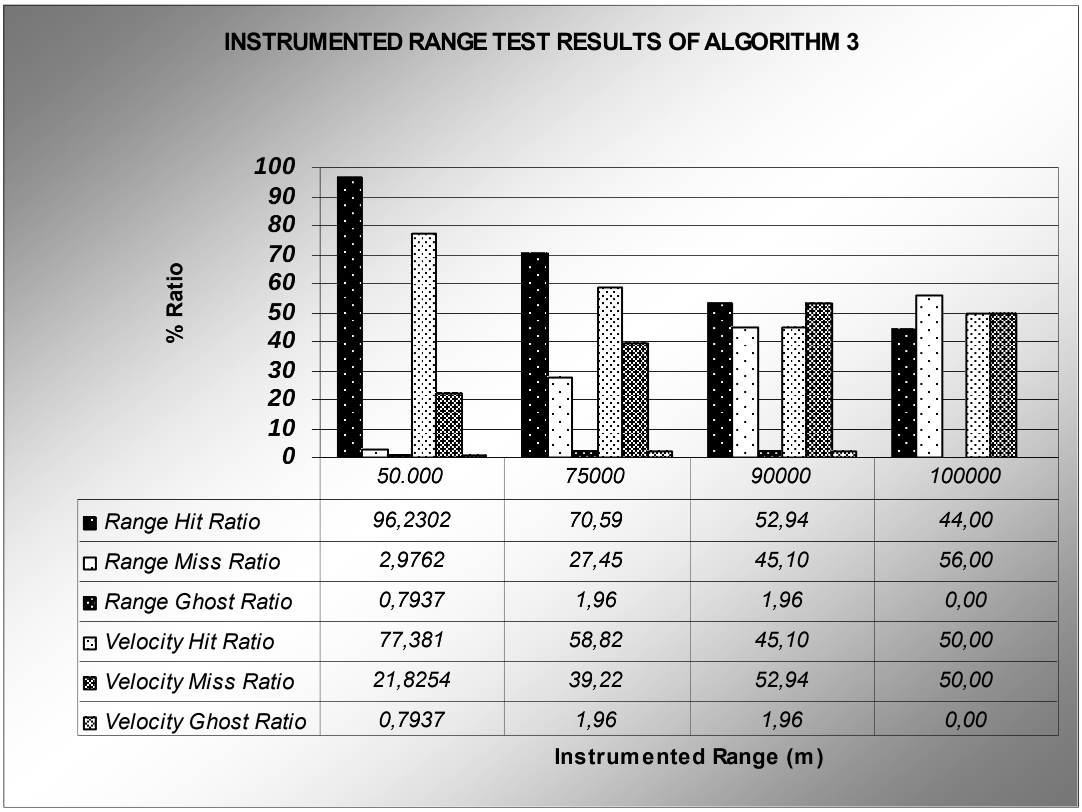
	50000	75000	90000	1E+05
Range Hit Ratio	83,432	52,99	44,97	36,17
Range Miss Ratio	15,1874	46,61	53,65	62,65
Range Ghost Ratio	1,3807	0,40	1,38	1,19
Velocity Hit Ratio	78,501	53,19	47,73	39,53
Velocity Miss Ratio	20,1183	46,41	50,89	59,29
Velocity Ghost Ratio	1,3807	0,40	1,38	1,19

Figure 13 Instrumented Range Test Results of Algorithm 1



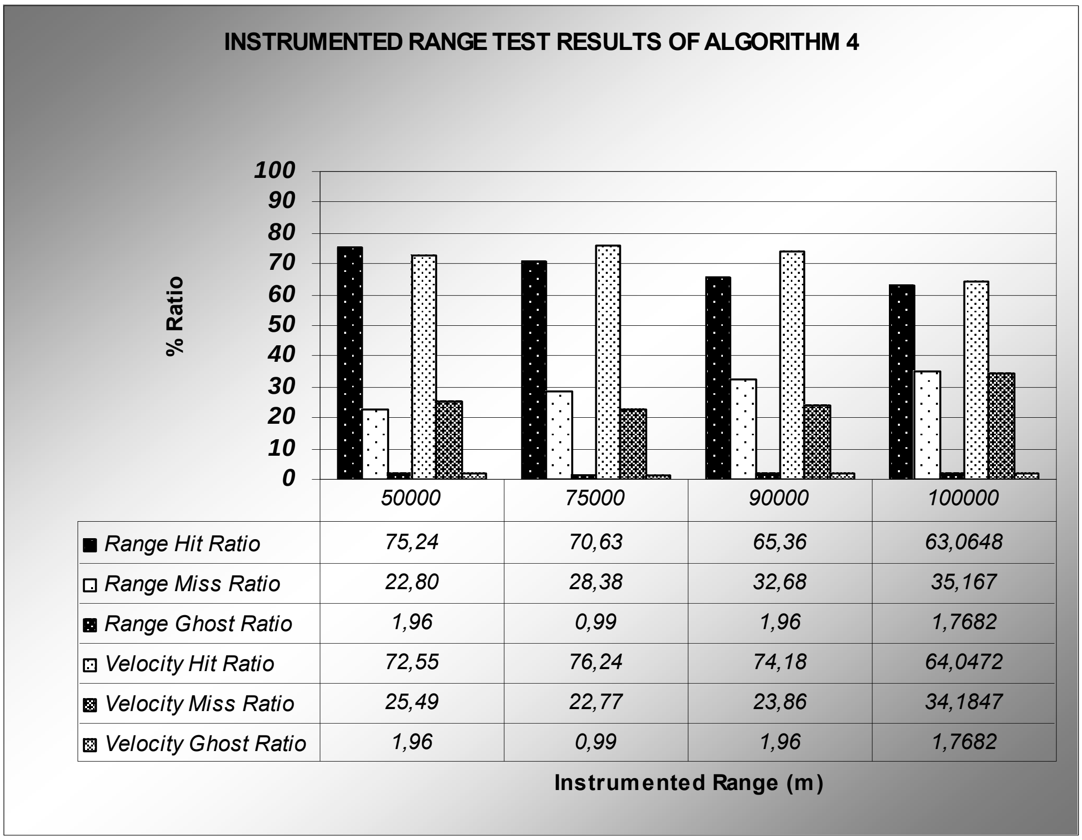
	50000	75000	90000	100000
Range Hit Ratio	79,7244	52,06	47,24	35,80
Range Miss Ratio	18,7008	46,17	51,18	61,48
Range Ghost Ratio	1,5748	1,77	1,57	2,72
Velocity Hit Ratio	79,3307	52,06	44,29	35,60
Velocity Miss Ratio	19,0945	46,17	54,13	61,67
Velocity Ghost Ratio	1,5748	1,77	1,57	2,72

Figure 14 Instrumented Range Test Results of Algorithm 2



	50.000	75000	90000	100000
Range Hit Ratio	96,2302	70,59	52,94	44,00
Range Miss Ratio	2,9762	27,45	45,10	56,00
Range Ghost Ratio	0,7937	1,96	1,96	0,00
Velocity Hit Ratio	77,381	58,82	45,10	50,00
Velocity Miss Ratio	21,8254	39,22	52,94	50,00
Velocity Ghost Ratio	0,7937	1,96	1,96	0,00

Figure 15 Instrumented Range Test Results of Algorithm 3



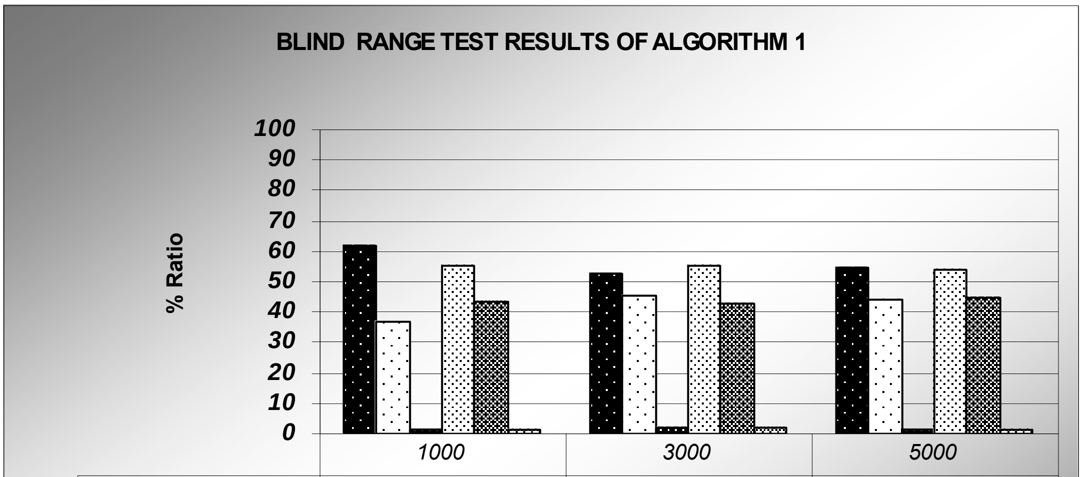
	50000	75000	90000	100000
Range Hit Ratio	75,24	70,63	65,36	63,0648
Range Miss Ratio	22,80	28,38	32,68	35,167
Range Ghost Ratio	1,96	0,99	1,96	1,7682
Velocity Hit Ratio	72,55	76,24	74,18	64,0472
Velocity Miss Ratio	25,49	22,77	23,86	34,1847
Velocity Ghost Ratio	1,96	0,99	1,96	1,7682

Figure 16 Instrumented Range Test Results of Algorithm 4

As it is seen from the graphs, the range detections decrease as the instrumented range is increased. The probability of detection is calculated as 0,95 at 45.000 m. If a target is located further than this value, its probability decreases so the signal received from this target will be zero. In the simulations, the targets are created randomly between 0 to instrumented range. If the instrumented range increases, the target will be out of the scope. The probability of a target being located in the detectable region 45 km for instrumented range of 50 km will be $\frac{45}{50} = 90\%$. For an instrumented range of 100 km, it will be $\frac{45}{100} = 45\%$, so over half of the targets may be located at invisible region. The difference between the instrumented range and minimum detectable range should be close for getting better results.

4.3 BLIND RANGE TESTS:

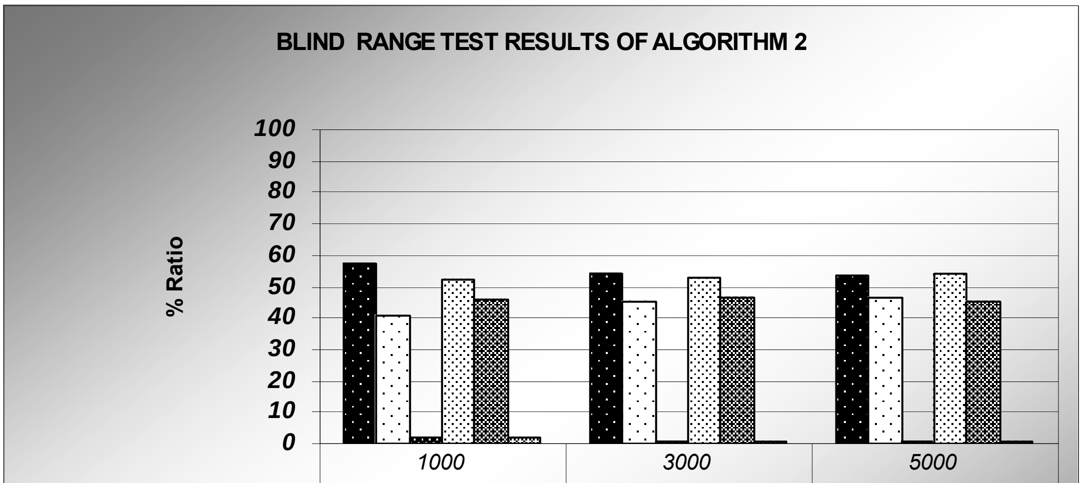
The minimum detectable range of radar is the distance from the radar that the system is unable to observe, also called as “blind zone”. The minimum detectable range tests are done for the ranges 1.000 m, 3.000 m, 5.000 m distances. The targets are created randomly. Some of the ranges of the targets may be in the minimum detectable range. So, as the minimum detectable gets larger, there will be an increment on the number of non-detected targets. The test results of algorithms for different minimum detectable ranges are given below:



	1000	3000	5000
Range Hit Ratio	61,81	52,55	54,55
Range Miss Ratio	36,61	45,49	44,27
Range Ghost Ratio	1,57	1,96	1,19
Velocity Hit Ratio	55,12	55,10	53,95
Velocity Miss Ratio	43,31	42,94	44,86
Velocity Ghost Ratio	1,57	1,96	1,19

Blind Range (m)

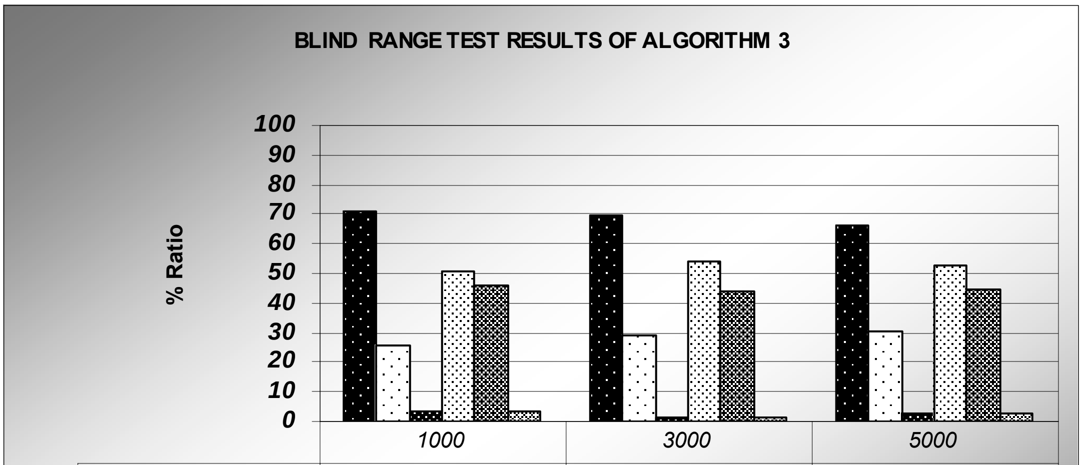
Figure 17 Blind Range Test Results Of Algorithm 1



	1000	3000	5000
Range Hit Ratio	57,14	54,17	53,19
Range Miss Ratio	40,70	45,04	46,41
Range Ghost Ratio	2,15	0,79	0,40
Velocity Hit Ratio	52,05	52,78	54,38
Velocity Miss Ratio	45,79	46,43	45,22
Velocity Ghost Ratio	2,15	0,79	0,40

Blind Range (m)

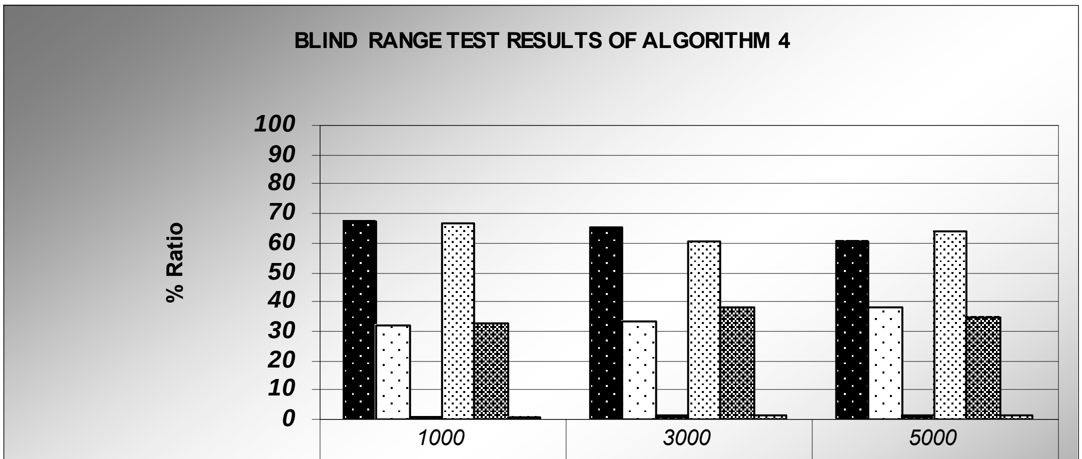
Figure 18 Blind Range Test Results of Algorithm 2



	1000	3000	5000
Range Hit Ratio	70,86	69,69	66,54
Range Miss Ratio	25,66	28,74	30,74
Range Ghost Ratio	3,47	1,57	2,72
Velocity Hit Ratio	50,58	54,33	52,92
Velocity Miss Ratio	45,95	44,09	44,36
Velocity Ghost Ratio	3,47	1,57	2,72

Blind Range (m)

Figure 19 Blind Range Test Results of Algorithm 3



	1000	3000	5000
Range Hit Ratio	67,30	65,61	60,63
Range Miss Ratio	31,91	33,20	37,80
Range Ghost Ratio	0,79	1,19	1,57
Velocity Hit Ratio	66,47	60,67	63,98
Velocity Miss Ratio	32,74	38,14	34,45
Velocity Ghost Ratio	0,79	1,19	1,57

Blind Range (m)

Figure 20 Blind Range Test Results of Algorithm 4

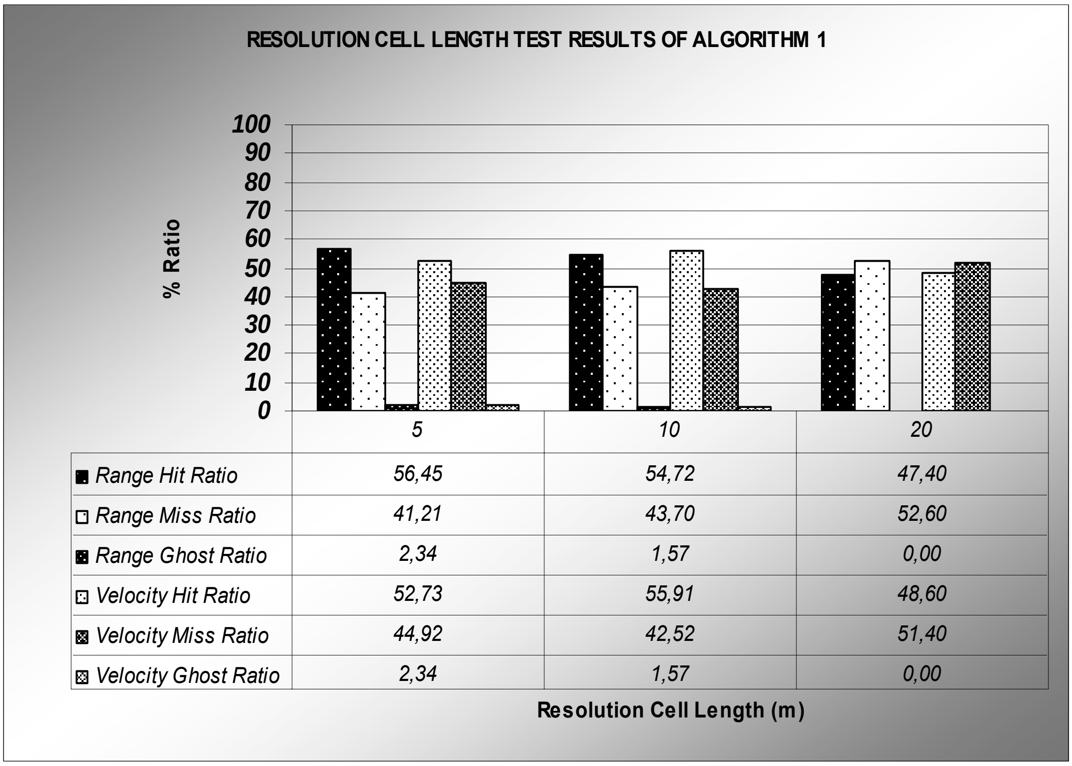
It is seen that there is not so much difference between 1000 m and 3000 m or 3000 m and 5000 m blind ranges. But there is a reasonable difference between 1000 m and 5000 m. As the blind range gets longer, a randomly target probability of corresponding to his zone will be greater. So, the long blind range has a negative effect on range performance of algorithms.

4.4 LENGTH OF RESOLUTION CELL TEST:

The interested range is divided into cells for detection and searches are done by range bins as

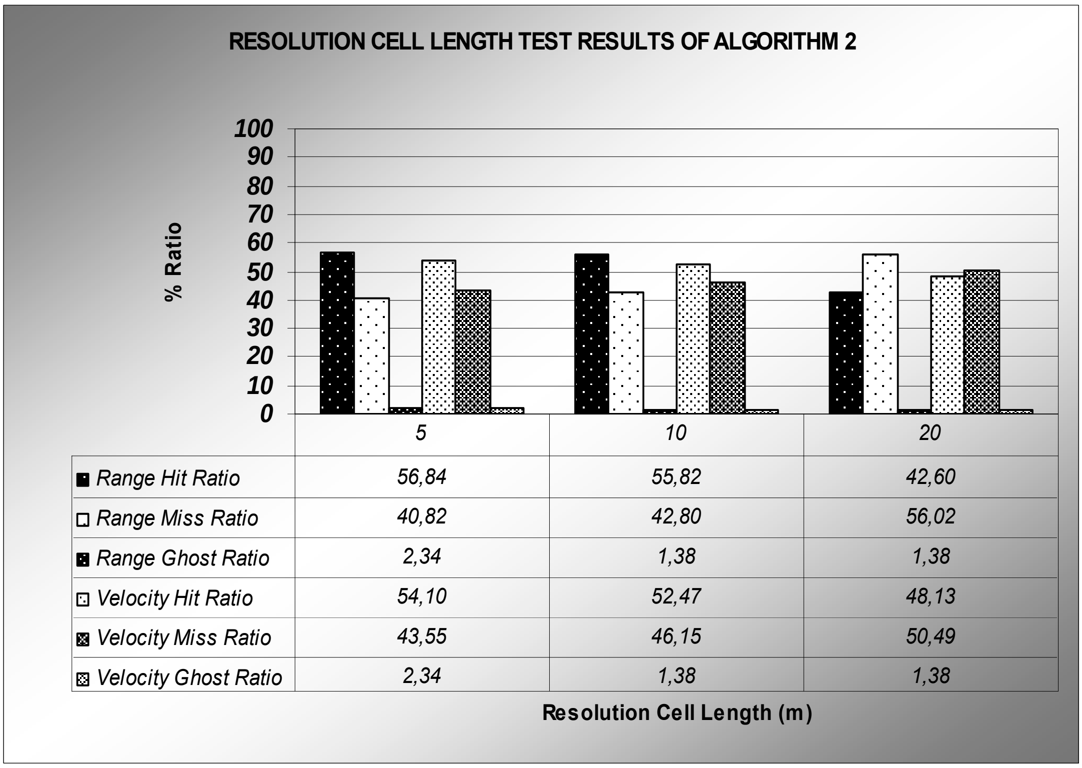
$$NumberOfRangeBins = \frac{InstrumentedRange}{LengthOf\ \mathrm{Re}\,solutionCell} \quad .(14)$$

The folding in range is also calculated in Range Bins type. Suppose that a target is located at range 16.253 m. For resolution cell with length = 5 m, its range bin will be 3250,6 and for length=10 m it will be 1625,3 and for 20 m it will be 812,65 . After rounding they will be 3251, 1626, 813 in range bins. When they are converted into true ranges they will be 16255, 16250, 16260 meters. Also after converting them into range bins there will also be a loss when converting into folded values and unfolding. So, as the length of resolution cell gets larger, the difference between folding and unfolding gets larger. Smaller resolution cell length yields more accurate results. The test results of algorithms for different resolution cell lengths are given below:



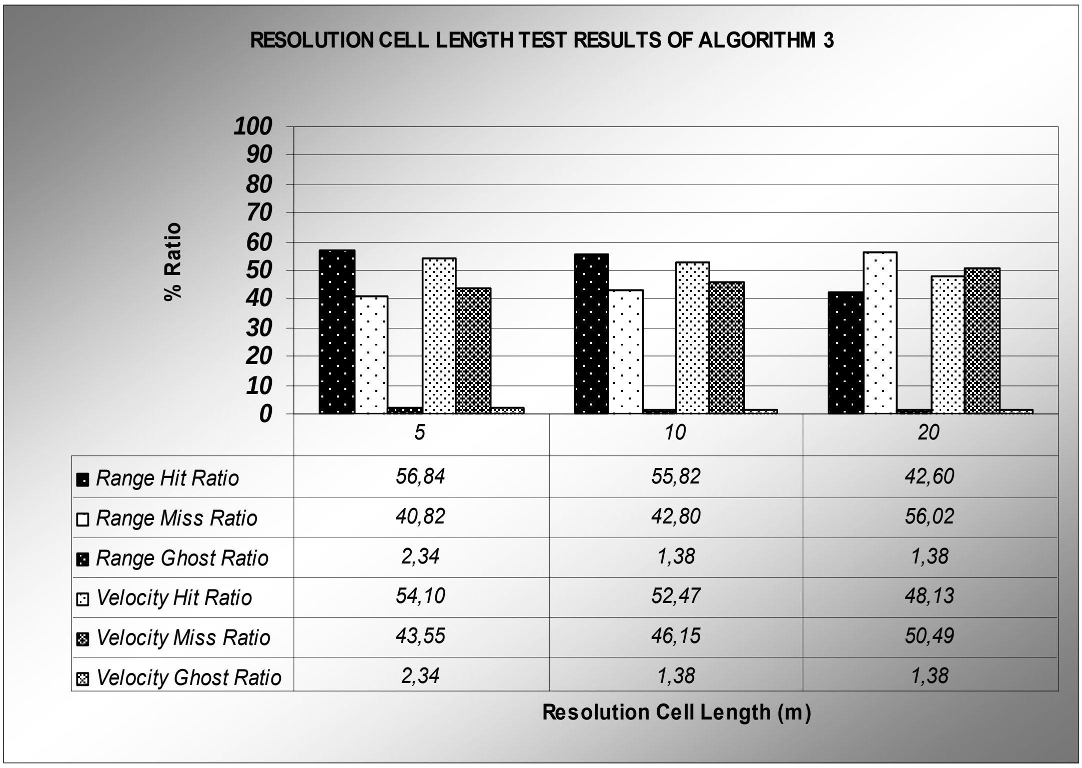
	5	10	20
Range Hit Ratio	56,45	54,72	47,40
Range Miss Ratio	41,21	43,70	52,60
Range Ghost Ratio	2,34	1,57	0,00
Velocity Hit Ratio	52,73	55,91	48,60
Velocity Miss Ratio	44,92	42,52	51,40
Velocity Ghost Ratio	2,34	1,57	0,00

Figure 21 Resolution Cell Length Test Results of Algorithm 1



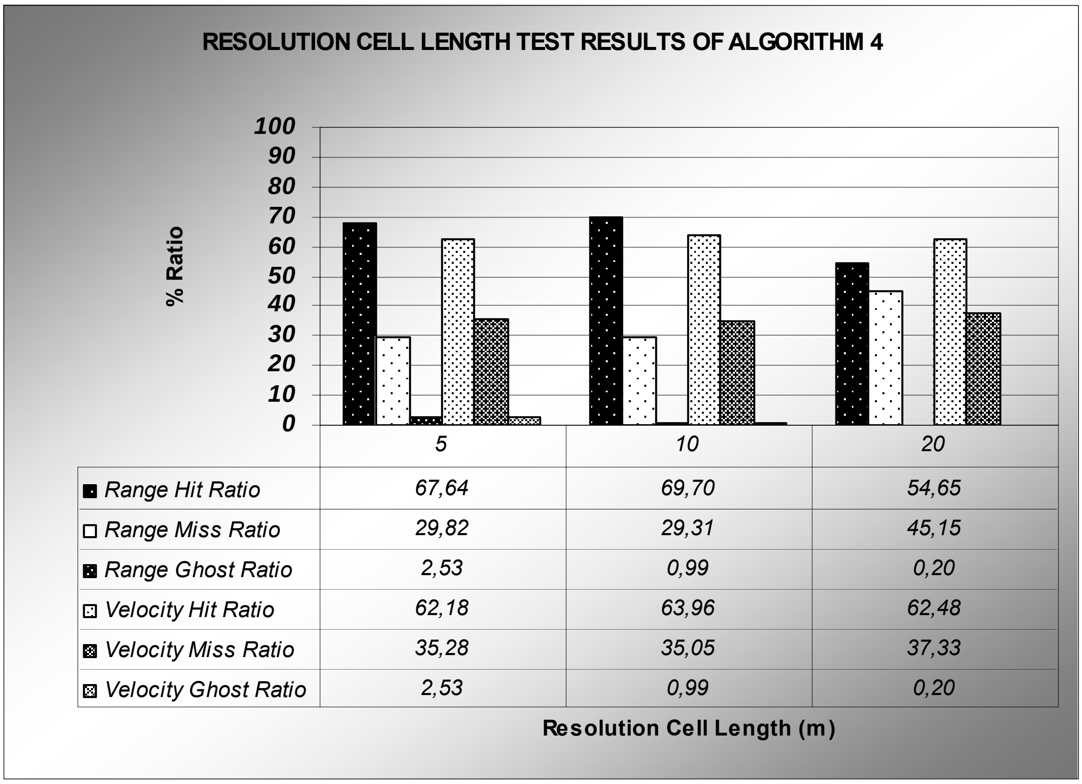
	5	10	20
Range Hit Ratio	56,84	55,82	42,60
Range Miss Ratio	40,82	42,80	56,02
Range Ghost Ratio	2,34	1,38	1,38
Velocity Hit Ratio	54,10	52,47	48,13
Velocity Miss Ratio	43,55	46,15	50,49
Velocity Ghost Ratio	2,34	1,38	1,38

Figure 22 Resolution Cell Length Test Results Of Algorithm 2



	5	10	20
Range Hit Ratio	56,84	55,82	42,60
Range Miss Ratio	40,82	42,80	56,02
Range Ghost Ratio	2,34	1,38	1,38
Velocity Hit Ratio	54,10	52,47	48,13
Velocity Miss Ratio	43,55	46,15	50,49
Velocity Ghost Ratio	2,34	1,38	1,38

Figure 23 Resolution Cell Length Test Results of Algorithm 3



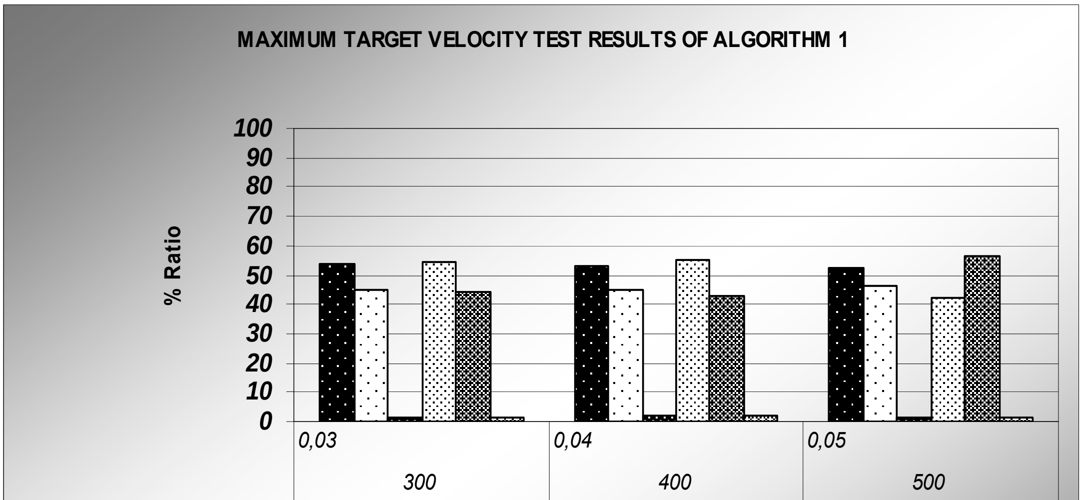
	5	10	20
Range Hit Ratio	67,64	69,70	54,65
Range Miss Ratio	29,82	29,31	45,15
Range Ghost Ratio	2,53	0,99	0,20
Velocity Hit Ratio	62,18	63,96	62,48
Velocity Miss Ratio	35,28	35,05	37,33
Velocity Ghost Ratio	2,53	0,99	0,20

Figure 24 Resolution Cell Length Test Results of Algorithm 4

According to the results, it can be said that there is not a significant difference between 5 m resolution length cell and 10 m resolution length cell. But, it is observed that there is a great decreasing in range results for 20 m length. In the comparison of actual results and detections, even one cell difference will be 20 m difference. Most of the detections will be eliminated by this great difference. From the results, it can be said that 10 m resolution cell length is optimum for this design.

4.5 MAXIMUM VELOCITY OF TARGETS:

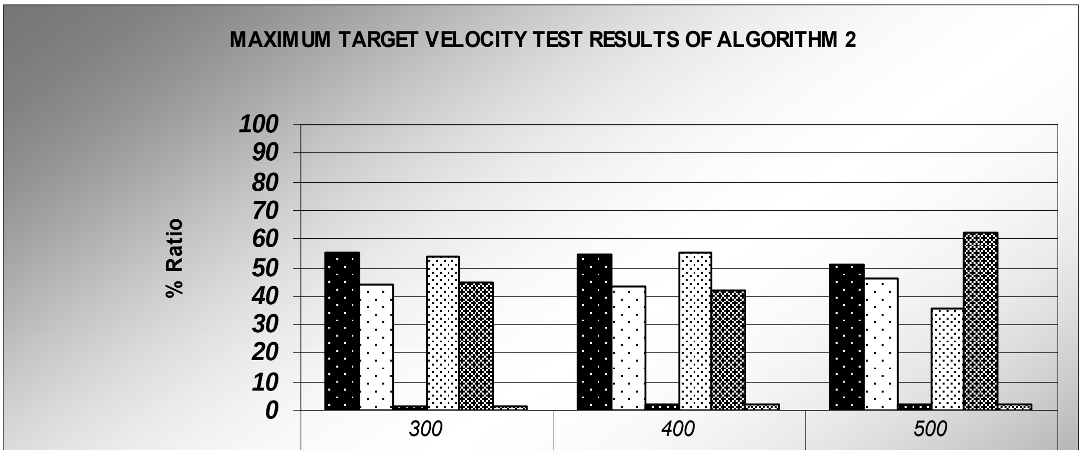
The algorithms are tested by maximum speed of targets with 300 m/sec, 400 m/sec, 500 m/sec . The simulator generates targets with the maximum speed of these values. The target speed can be both positive, which means the target is closing to the system or negative values, which means the target is going away from the system. So the system is tested for both positive and negative target detections. As the velocity gets higher, a slightly decrement on performances is observed. The test results of algorithms for different maximum detectable velocities are given below:



	300	400	500
Range Hit Ratio	54,04	53,05	52,66
Range Miss Ratio	44,58	45,19	45,96
Range Ghost Ratio	1,38	1,77	1,38
Velocity Hit Ratio	54,64	55,21	42,01
Velocity Miss Ratio	43,98	43,03	56,61
Velocity Ghost Ratio	1,38	1,77	1,38

Maximum± Target Velocity (m/sec)

Figure 25 Maximum Target Velocity Test Results Of Algorithm 1



	300	400	500
Range Hit Ratio	54,94	54,79	51,17
Range Miss Ratio	43,87	43,05	46,48
Range Ghost Ratio	1,19	2,15	2,34
Velocity Hit Ratio	53,95	55,58	35,55
Velocity Miss Ratio	44,86	42,27	62,11
Velocity Ghost Ratio	1,19	2,15	2,34

Maximum± Target Velocity (m/sec)

Figure 26 Maximum Target Velocity Test Results Of Algorithm 2

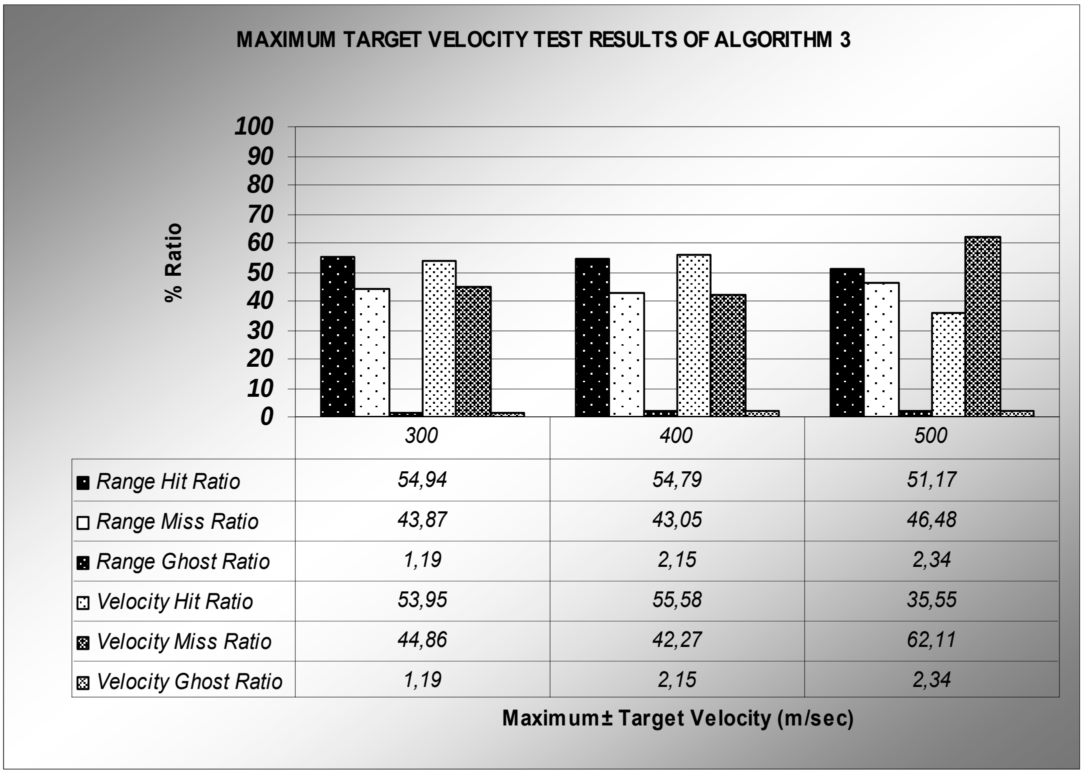


Figure 27 Maximum Target Velocity Test Results of Algorithm 3

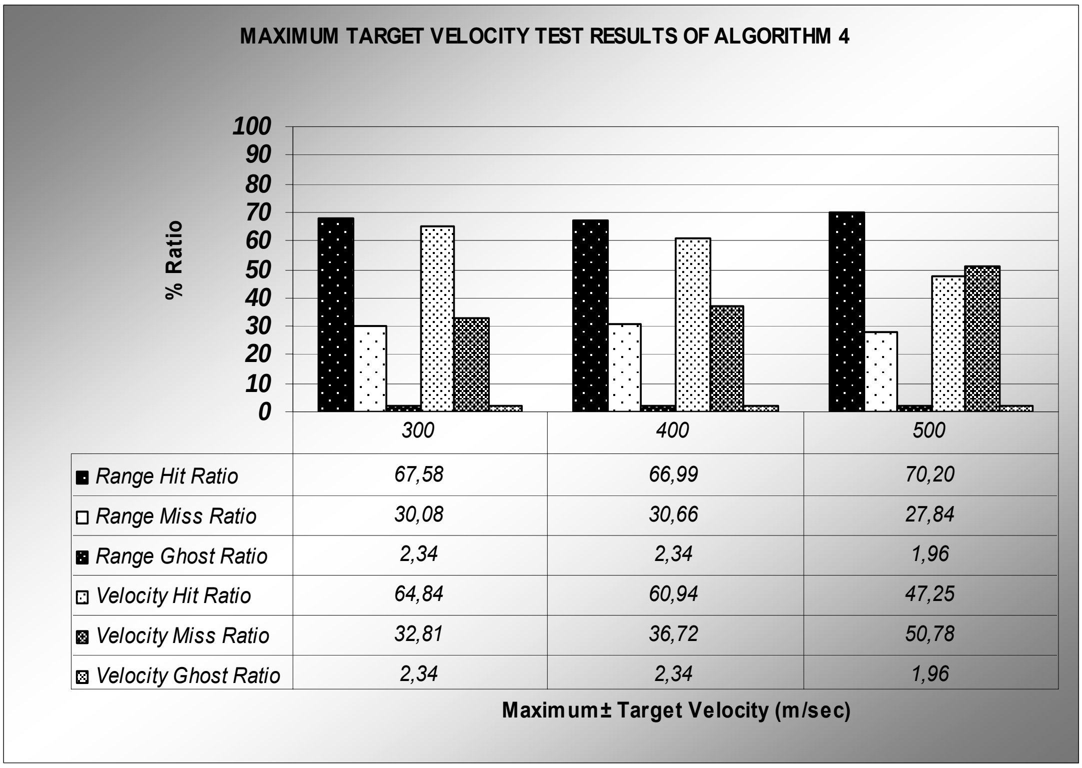
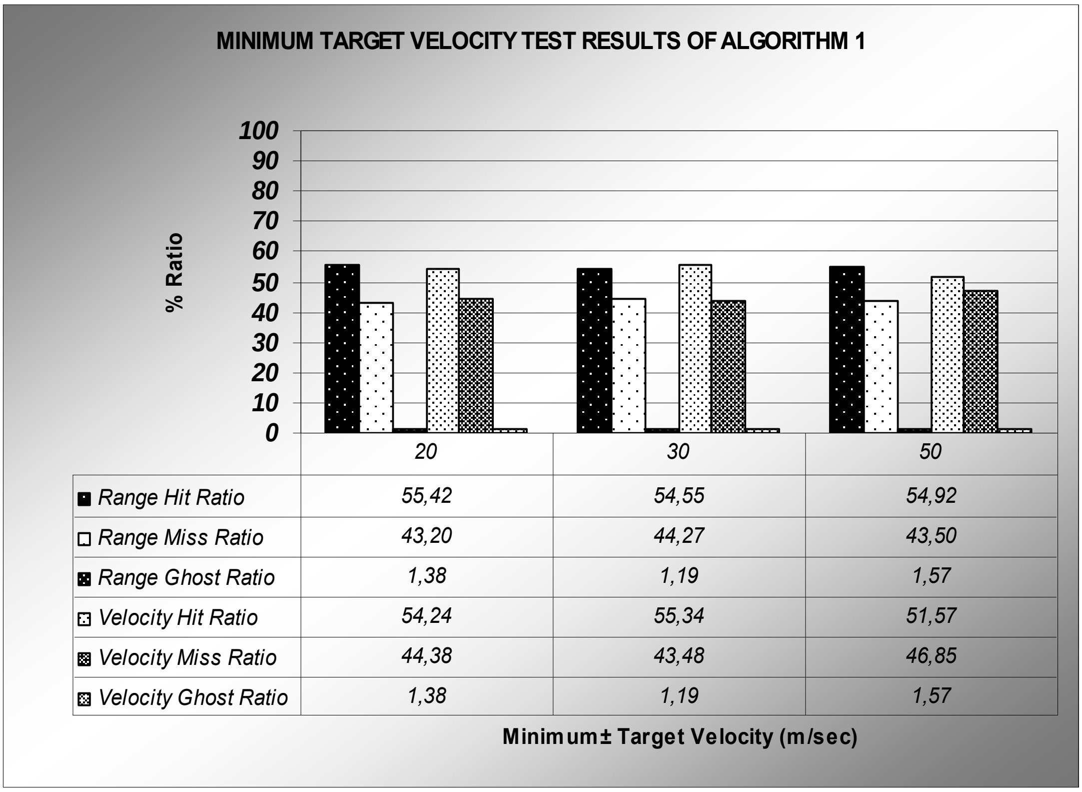


Figure 28 Maximum Target Velocity Test Results of Algorithm 4

From the graphs, it is seen that as the maximum target velocities get higher, the velocity detections decrease. The maximum detectable velocity should be not so much greater with respect to the used PRI. The received velocity signals are folded values. As the maximum detectable velocity gets higher, the folding value of received signal will be higher. So resolving this value will be harder. Also detecting higher velocities require higher PRFs. Used PRI set is not suitable for higher velocities.

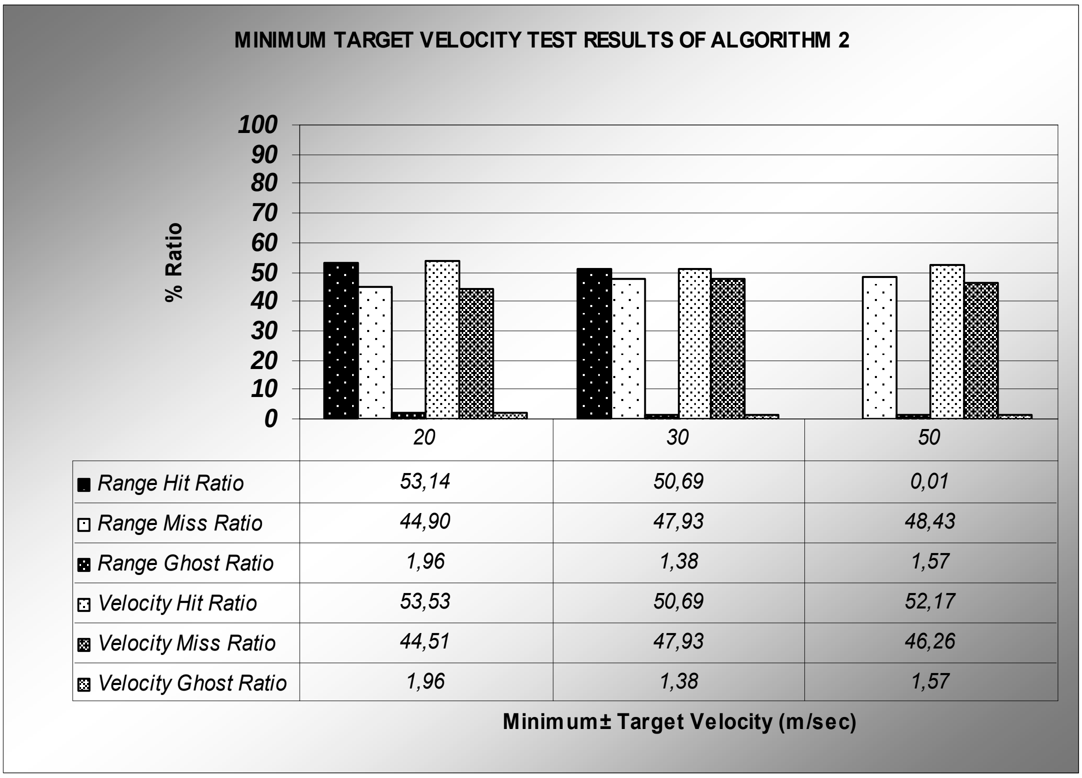
4.6 MINIMUM VELOCITY OF TARGETS TEST:

The algorithms are tested by minimum speed of targets with 20 m/sec, 30 m/sec, 50 m/sec . The simulator generates target velocities that may vary from 0 to the entered ± maximum detectable velocity. The target speed can be both positive, which means the target is closing to the system or negative values, which means the target is going away from the system. So the system is tested for both positive and negative target detections. If a target has the velocity less than the minimum detectable velocity, it will be neglected by the system and there will be no process on this target. For example a target has the velocity with 40 m/sec will be processed by the minimum detectable velocities equal to 20m/sec and 30 m/sec and it will be neglected by minimum detectable velocity is equal to 50 m/sec . So, as the minimum detectable gets larger, the probability of correspondence of the randomly created target velocities will be increased. So it can be said that the increment on the minimum detectable range causes decrement on the system performances. The test results of algorithms for different minimum detectable velocities are given below:



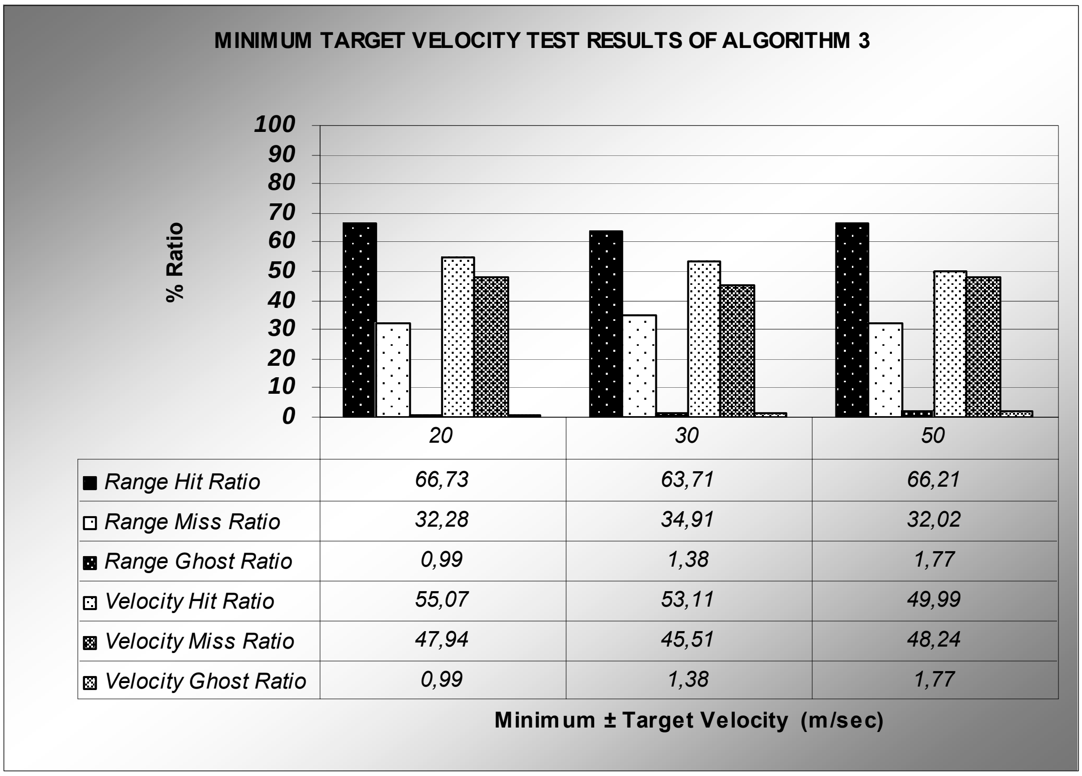
	20	30	50
Range Hit Ratio	55,42	54,55	54,92
Range Miss Ratio	43,20	44,27	43,50
Range Ghost Ratio	1,38	1,19	1,57
Velocity Hit Ratio	54,24	55,34	51,57
Velocity Miss Ratio	44,38	43,48	46,85
Velocity Ghost Ratio	1,38	1,19	1,57

Figure 29 Minimum Target Velocity Test Results of Algorithm 1



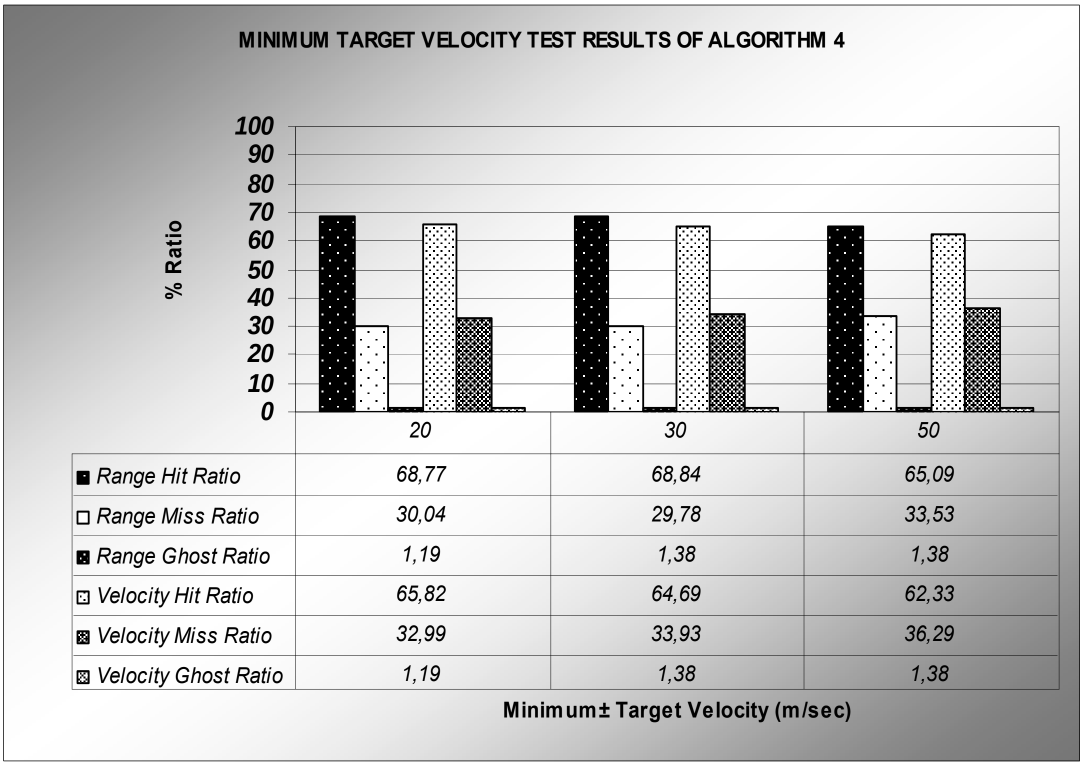
	20	30	50
Range Hit Ratio	53,14	50,69	0,01
Range Miss Ratio	44,90	47,93	48,43
Range Ghost Ratio	1,96	1,38	1,57
Velocity Hit Ratio	53,53	50,69	52,17
Velocity Miss Ratio	44,51	47,93	46,26
Velocity Ghost Ratio	1,96	1,38	1,57

Figure 30 Minimum Target Velocity Test Results of Algorithm 2



	20	30	50
Range Hit Ratio	66,73	63,71	66,21
Range Miss Ratio	32,28	34,91	32,02
Range Ghost Ratio	0,99	1,38	1,77
Velocity Hit Ratio	55,07	53,11	49,99
Velocity Miss Ratio	47,94	45,51	48,24
Velocity Ghost Ratio	0,99	1,38	1,77

Figure 31 Minimum Target Velocity Test Results of Algorithm 3



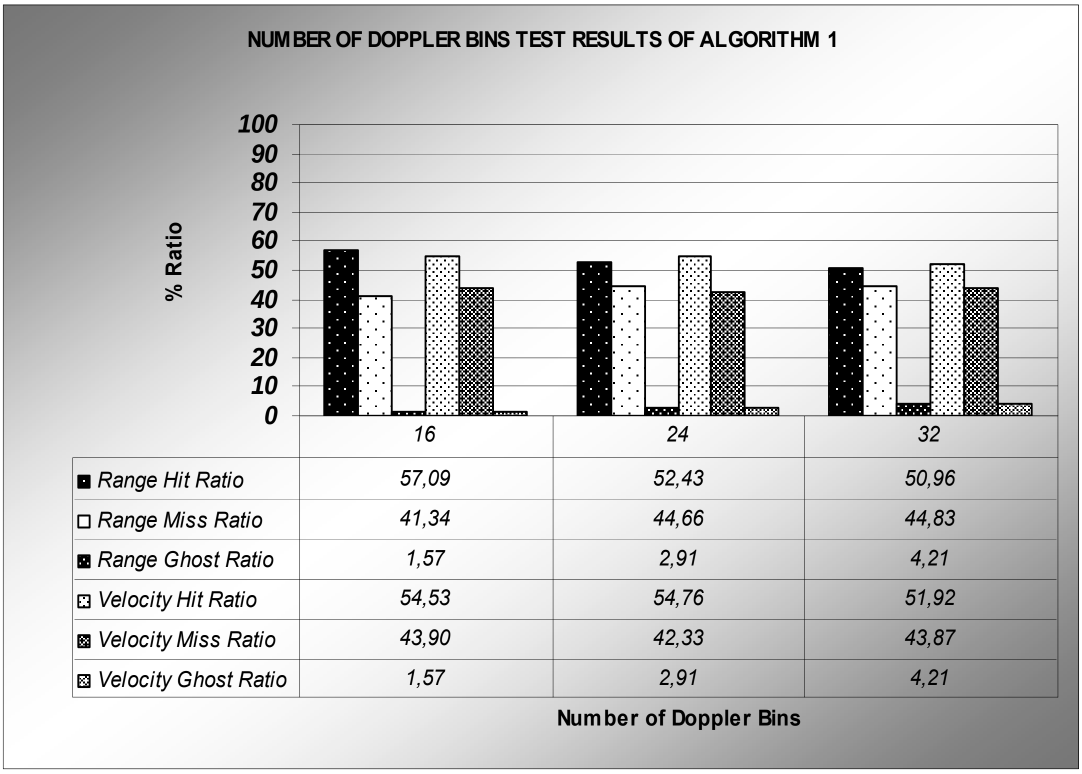
	20	30	50
Range Hit Ratio	68,77	68,84	65,09
Range Miss Ratio	30,04	29,78	33,53
Range Ghost Ratio	1,19	1,38	1,38
Velocity Hit Ratio	65,82	64,69	62,33
Velocity Miss Ratio	32,99	33,93	36,29
Velocity Ghost Ratio	1,19	1,38	1,38

Figure 32 Minimum Target Velocity Test Results of Algorithm 4

The targets moving with velocities less than minimum detectable velocities will be ignored so they will not be detected. The randomly created target velocities probability of being in the minimum detectable range will be high for high minimum detectable range. For 20 m/sec, it will be $\frac{20}{400} = 5\%$ but for 50 m/sec, it will be $\frac{50}{400} = 12,5\%$. For good performance, minimum detectable velocity should be small.

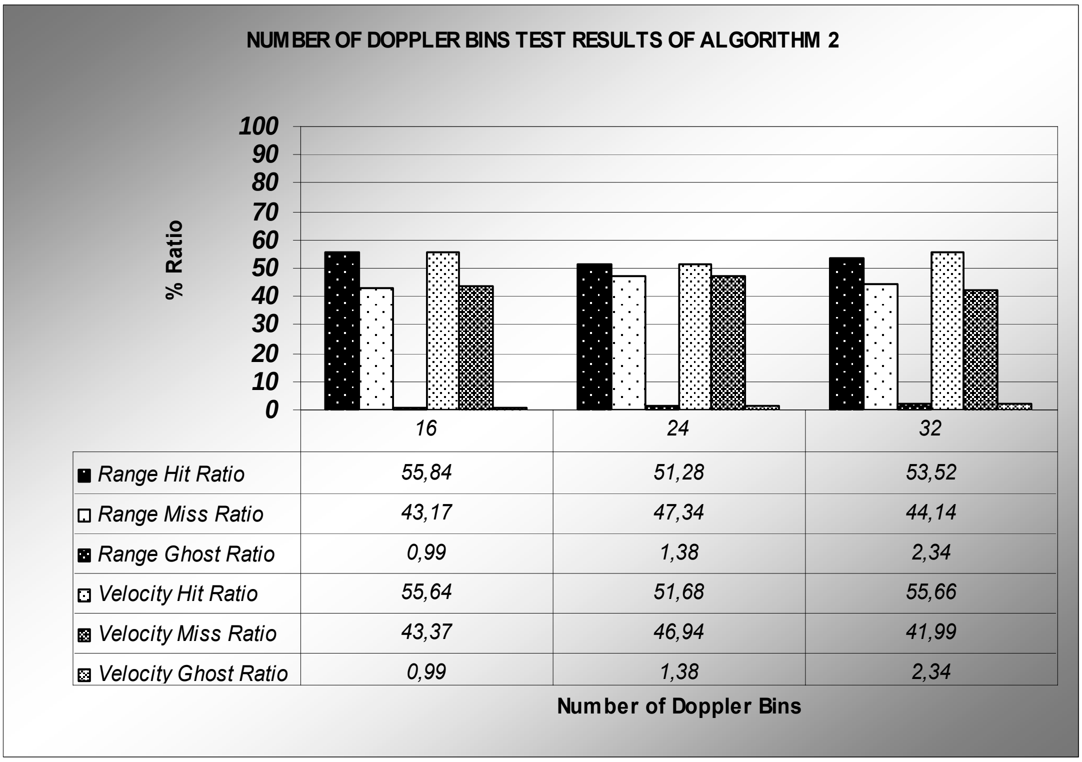
4.7 NUMBER OF DOPPLER BINS TEST:

The algorithms are tested by number of Doppler bins 16, 24, 32. The number of Doppler bins increases the resolution of velocity .So greater Doppler bin numbers provides more accurate ranges. The Doppler bin resolution (D_{res}) of a system is given by formula (11), where D_{res} is the number of Doppler bins. For a specific PRI, maximum unambiguous velocity is given by formula (10). The unambiguous velocity is distributed into the Doppler bins. As the number of Doppler bin number increase, the velocity fraction corresponds to the each bin is decreased, so this provides a better resolution. The velocity is folded through the detection and the received part is detected as Doppler bins by the system. In the Doppler bins, the velocities corresponding to the zero Doppler are neglected. As the number of Doppler bins increased, the ratio of velocities corresponding to the zero Doppler bin is decreased, so it causes an increment on performance. Also it causes better results by the increment of accuracy and velocity resolution. The test results of algorithms for different number of range bins are given below:



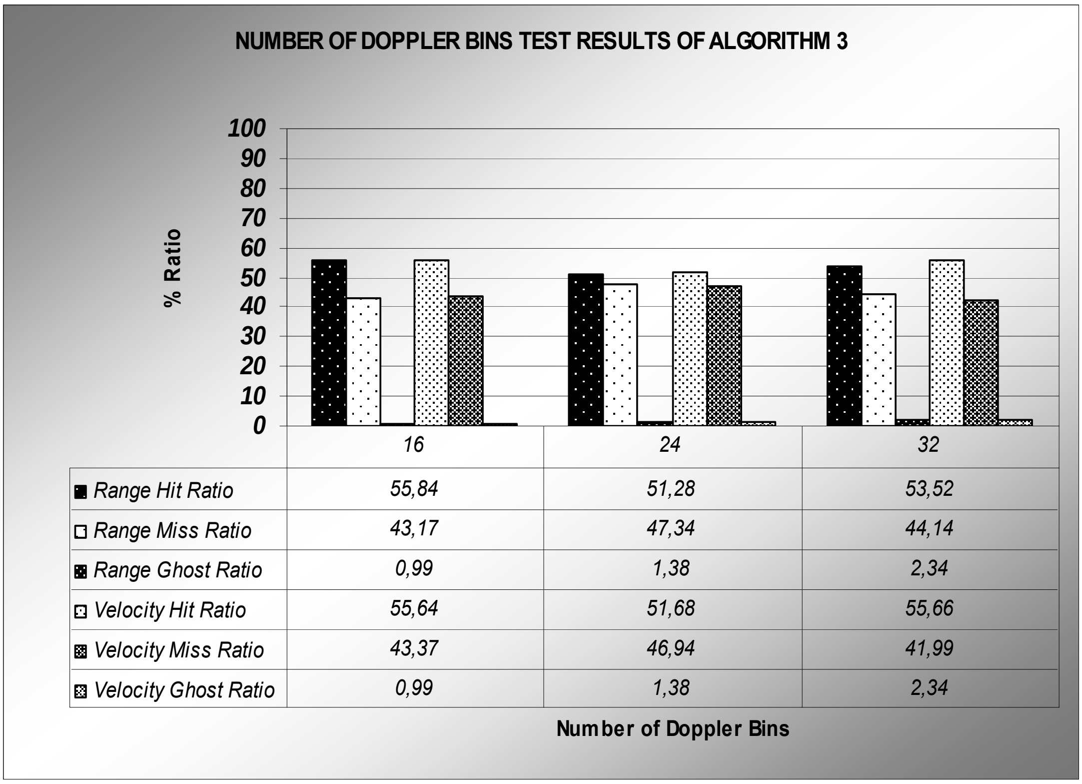
	16	24	32
Range Hit Ratio	57,09	52,43	50,96
Range Miss Ratio	41,34	44,66	44,83
Range Ghost Ratio	1,57	2,91	4,21
Velocity Hit Ratio	54,53	54,76	51,92
Velocity Miss Ratio	43,90	42,33	43,87
Velocity Ghost Ratio	1,57	2,91	4,21

Figure 33 Number of Doppler Bin Test Results of Algorithm 1



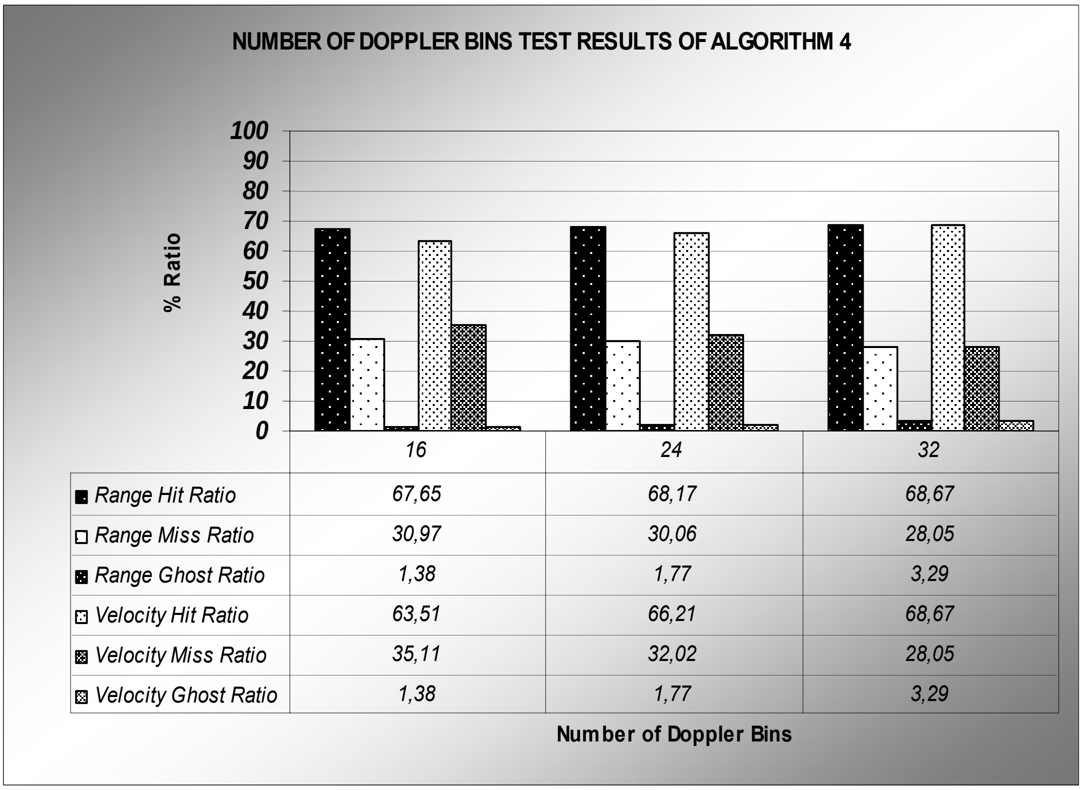
	16	24	32
Range Hit Ratio	55,84	51,28	53,52
Range Miss Ratio	43,17	47,34	44,14
Range Ghost Ratio	0,99	1,38	2,34
Velocity Hit Ratio	55,64	51,68	55,66
Velocity Miss Ratio	43,37	46,94	41,99
Velocity Ghost Ratio	0,99	1,38	2,34

Figure 34 Number of Doppler Bin Test Results of Algorithm 2



	16	24	32
Range Hit Ratio	55,84	51,28	53,52
Range Miss Ratio	43,17	47,34	44,14
Range Ghost Ratio	0,99	1,38	2,34
Velocity Hit Ratio	55,64	51,68	55,66
Velocity Miss Ratio	43,37	46,94	41,99
Velocity Ghost Ratio	0,99	1,38	2,34

Figure 35 Number of Doppler Bin Test Results of Algorithm 3

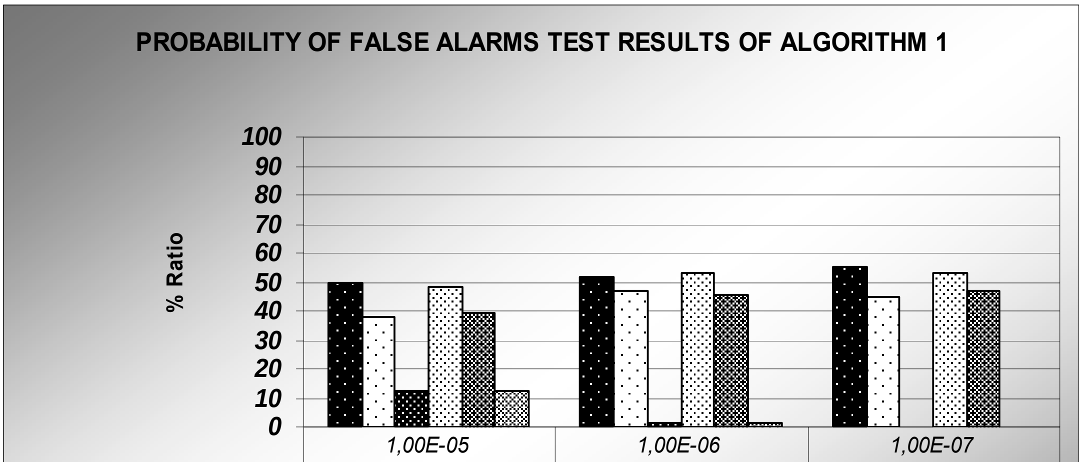


	16	24	32
Range Hit Ratio	67,65	68,17	68,67
Range Miss Ratio	30,97	30,06	28,05
Range Ghost Ratio	1,38	1,77	3,29
Velocity Hit Ratio	63,51	66,21	68,67
Velocity Miss Ratio	35,11	32,02	28,05
Velocity Ghost Ratio	1,38	1,77	3,29

Figure 36 Number of Doppler Bin Test Results of Algorithm 4

4.8 PROBABILITY OF FALSE ALARMS (Pfa) TEST:

The system is tested by different levels of false alarm rates. Sometimes the system may receive or produce non existing target signals due to the noise and clutters and may cause false alarms. The probability of false alarms is something randomly occurring. The system generates false detections due to the level of this probability and they may cause ghost detections. The algorithms are tested for probability of false alarms equal to 1e-5, 1e-6, and 1e-7. As the probability gets smaller, the number of false alarms and the number of ghost detections will be decreased. The test results of algorithms for different false alarm rates are given below:



	1,00E-05	1,00E-06	1,00E-07
Range Hit Ratio	49,48	51,87	55,20
Range Miss Ratio	37,94	46,75	44,80
Range Ghost Ratio	12,59	1,38	0,00
Velocity Hit Ratio	48,43	53,25	53,40
Velocity Miss Ratio	38,99	45,36	46,60
Velocity Ghost Ratio	12,59	1,38	0,00

Probability of False Alarms

Figure 37 Probability of False Alarms Test Results of Algorithm 1

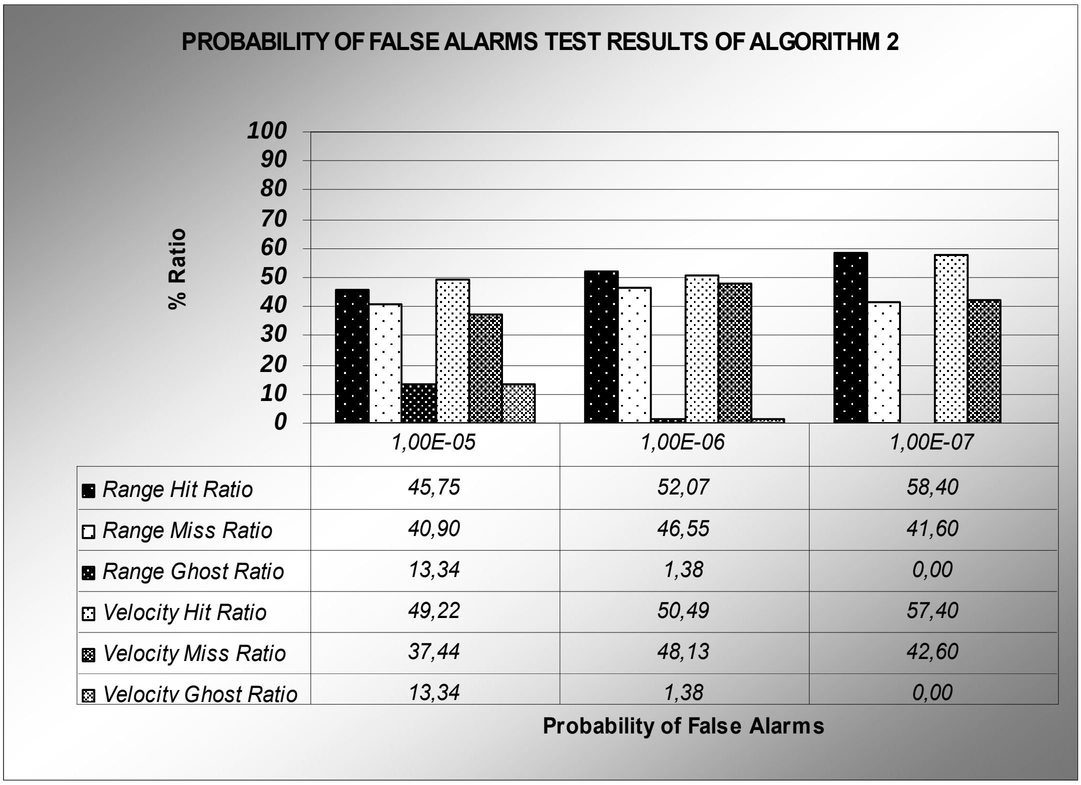


Figure 38 Probability of False Alarms Test Results of Algorithm 2

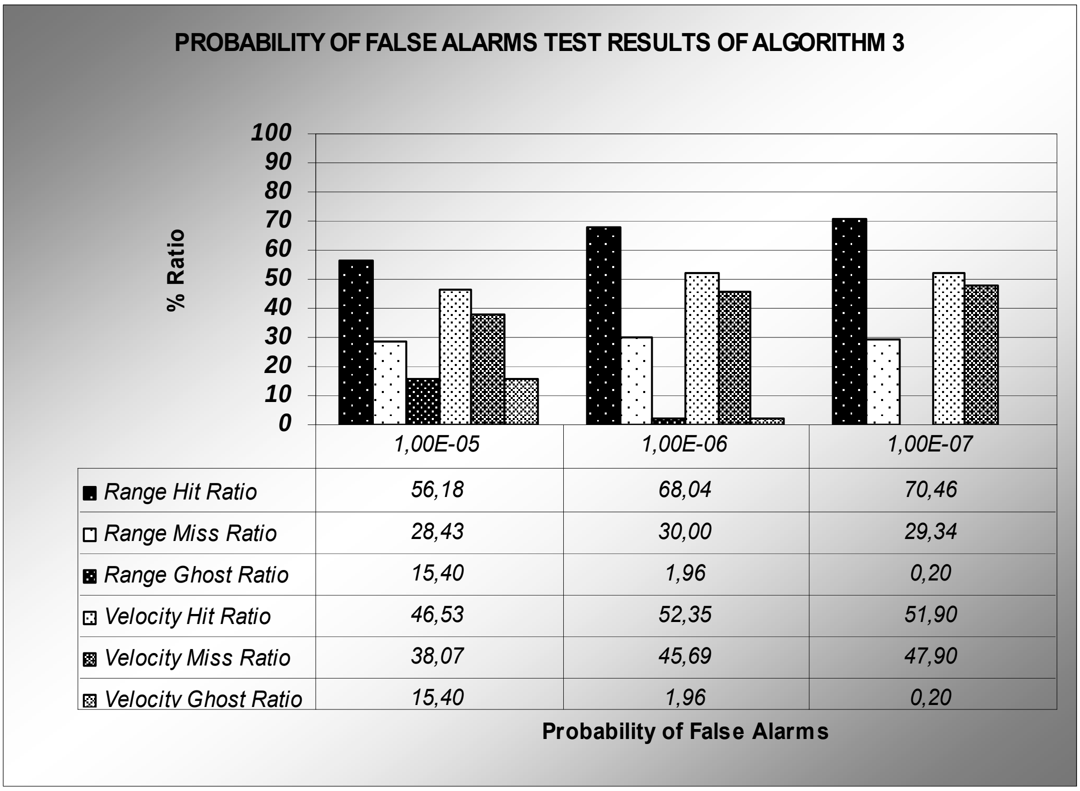


Figure 39 Probability of False Alarms Test Results of Algorithm 3

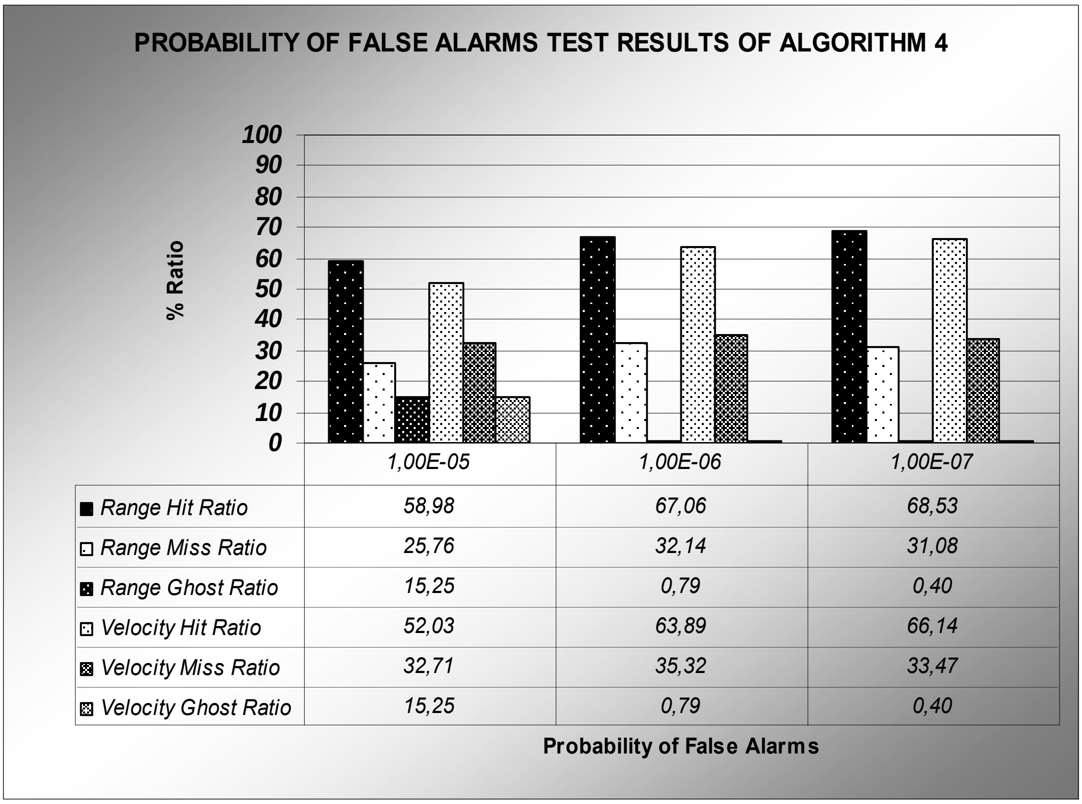
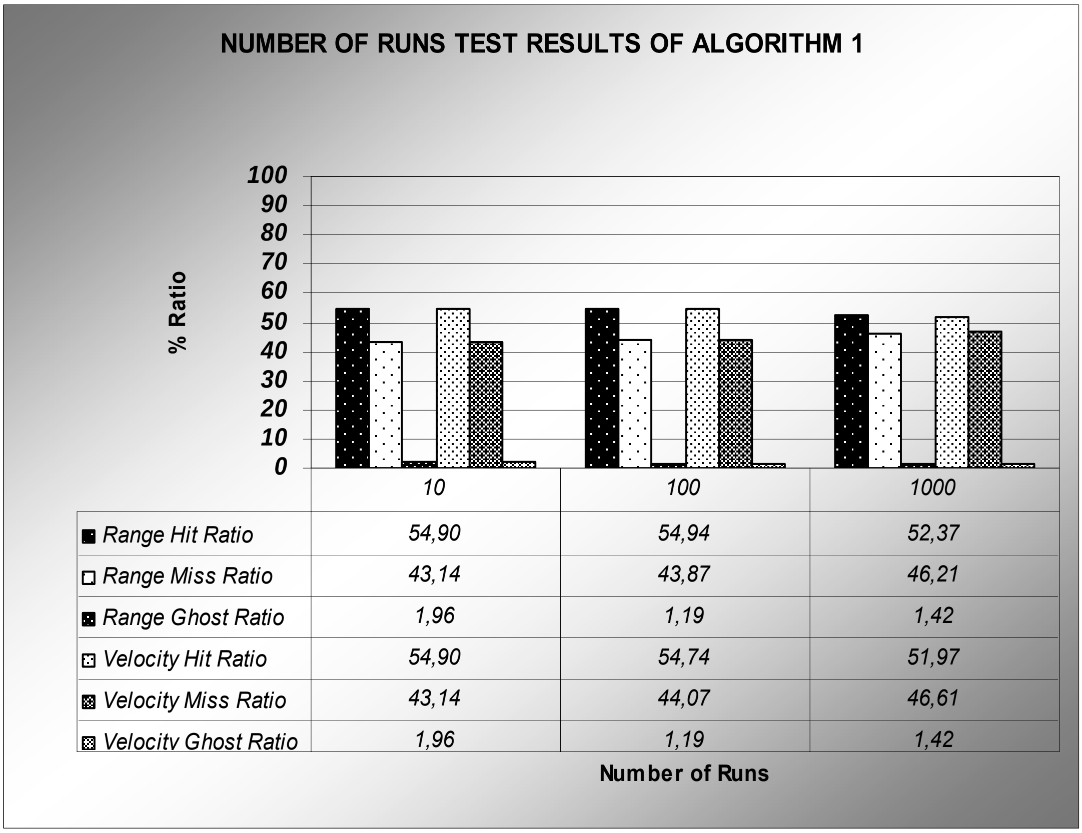


Figure 40 Probability of False Alarms Test Results of Algorithm 4

The observed ghost ratio gets higher as the probability gets higher. It is seen that it has a negative effect on the range and velocity detection performance. In the 1e-7 probability of false alarm value, there is almost none ghost value. In actual systems, usually 1e-6 is used.

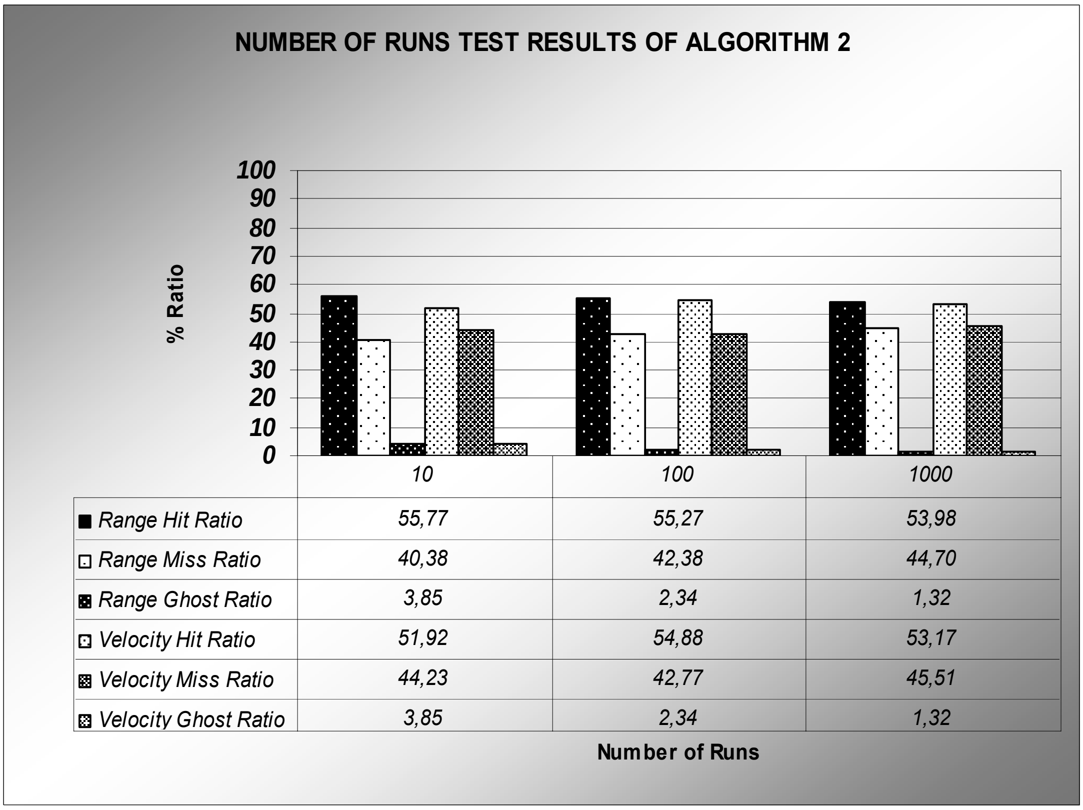
4.9 NUMBER OF RUNS TEST:

The system is tested by number of runs equal to 10, 100, 1000 respectively. As the tests are all randomly and statistically, increasing the number of tests gives more accurate and stable results. So for better tests, the number of runs must be increased. In the overall tests usually 100 runs are used for getting stable results. The test results of algorithms for different number of runs are given below:



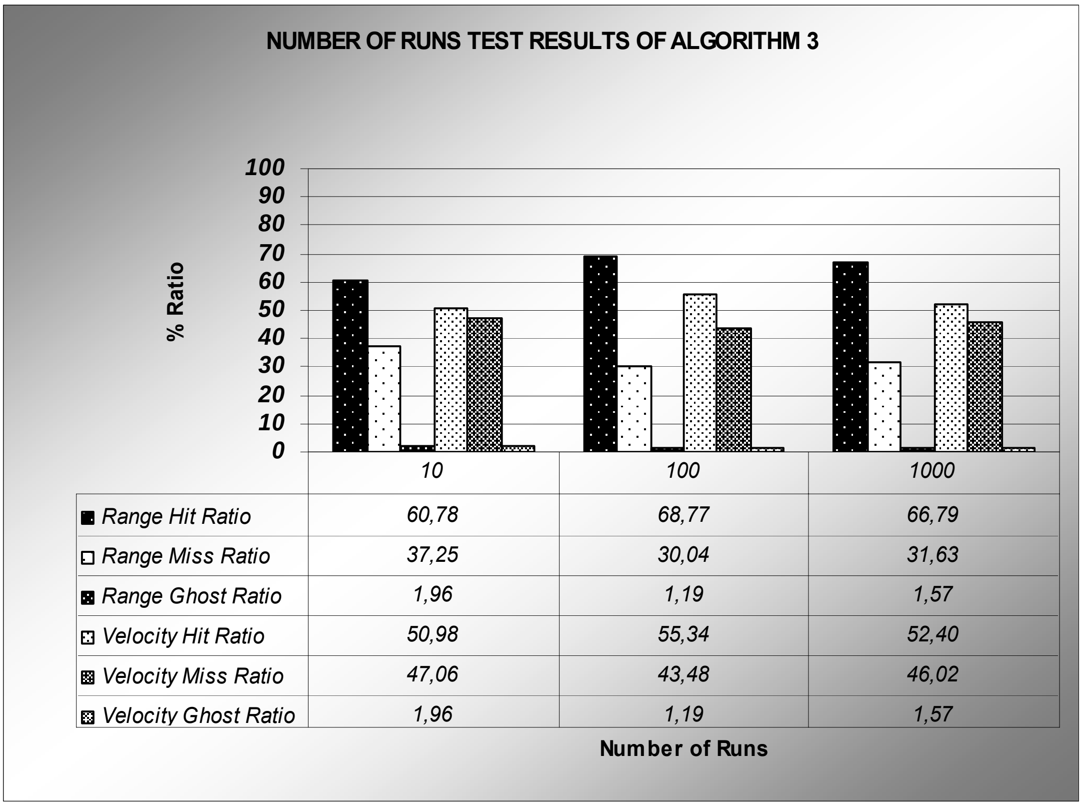
	10	100	1000
Range Hit Ratio	54,90	54,94	52,37
Range Miss Ratio	43,14	43,87	46,21
Range Ghost Ratio	1,96	1,19	1,42
Velocity Hit Ratio	54,90	54,74	51,97
Velocity Miss Ratio	43,14	44,07	46,61
Velocity Ghost Ratio	1,96	1,19	1,42

Figure 41 Number of RunsTest Results of Algorithm 1



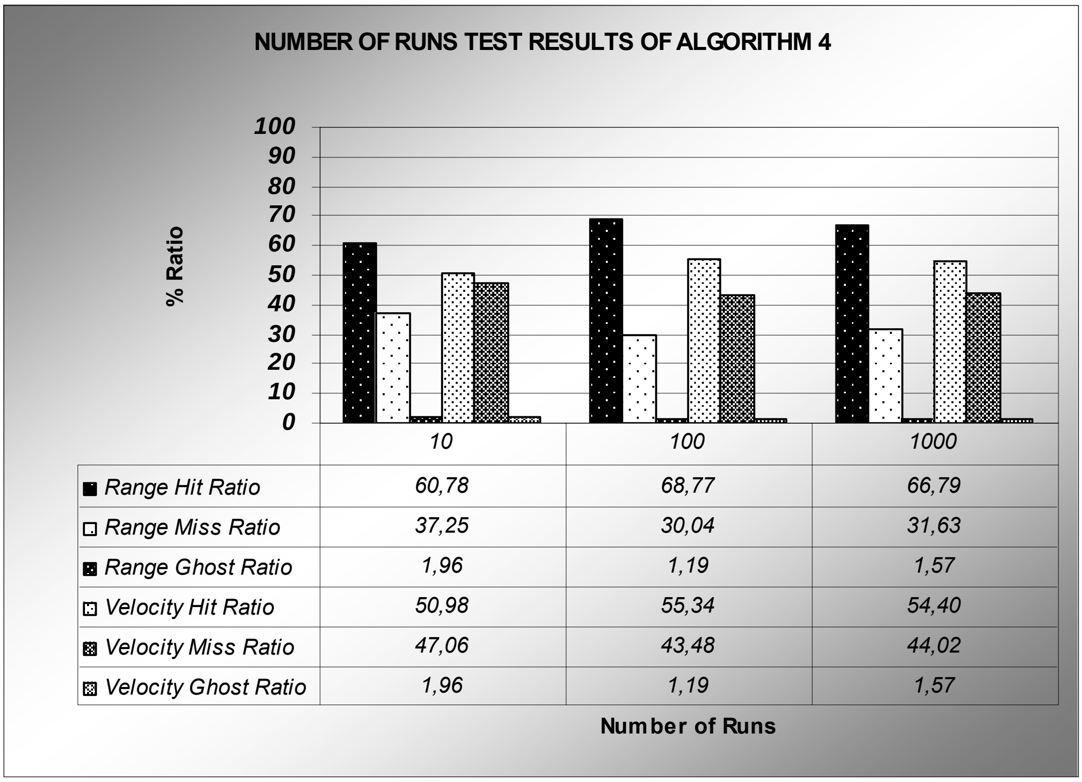
	10	100	1000
Range Hit Ratio	55,77	55,27	53,98
Range Miss Ratio	40,38	42,38	44,70
Range Ghost Ratio	3,85	2,34	1,32
Velocity Hit Ratio	51,92	54,88	53,17
Velocity Miss Ratio	44,23	42,77	45,51
Velocity Ghost Ratio	3,85	2,34	1,32

Figure 42 Number of Run Test Results of Algorithm 2



	10	100	1000
Range Hit Ratio	60,78	68,77	66,79
Range Miss Ratio	37,25	30,04	31,63
Range Ghost Ratio	1,96	1,19	1,57
Velocity Hit Ratio	50,98	55,34	52,40
Velocity Miss Ratio	47,06	43,48	46,02
Velocity Ghost Ratio	1,96	1,19	1,57

Figure 43 Number of Run Test Results of Algorithm 3



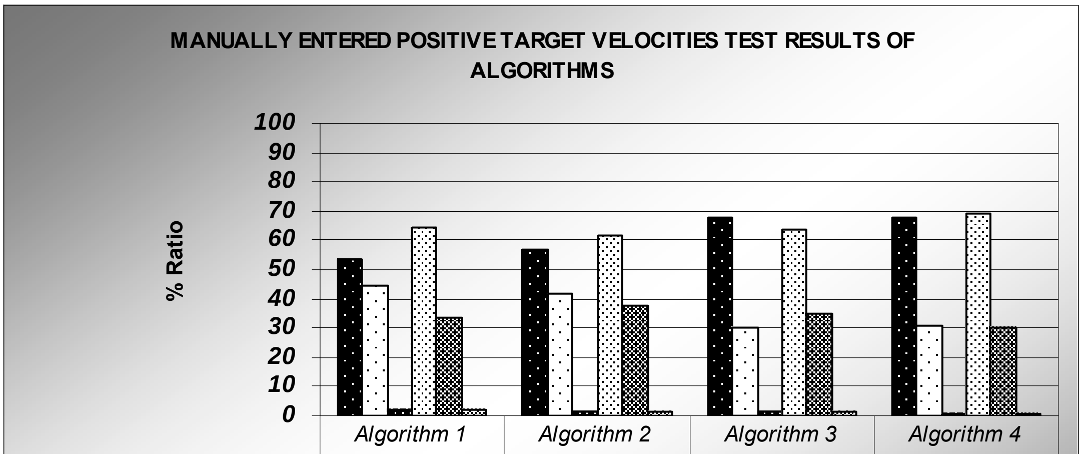
	10	100	1000
Range Hit Ratio	60,78	68,77	66,79
Range Miss Ratio	37,25	30,04	31,63
Range Ghost Ratio	1,96	1,19	1,57
Velocity Hit Ratio	50,98	55,34	54,40
Velocity Miss Ratio	47,06	43,48	44,02
Velocity Ghost Ratio	1,96	1,19	1,57

Figure 44 Number of Run Test Results of Algorithm 4

In tests, as the number of runs gets higher, the test results get more stable. In the tests, it is seen that 10 runs is not sufficient for stable results. 100 runs produce similar results as 1000 runs. Number of 100 runs is optimal for stable results with minimum runs. Because of this, 100 run preferred in most of the algorithm test.

4.10 MANUALLY ENTERED TARGET VELOCITIES TEST:

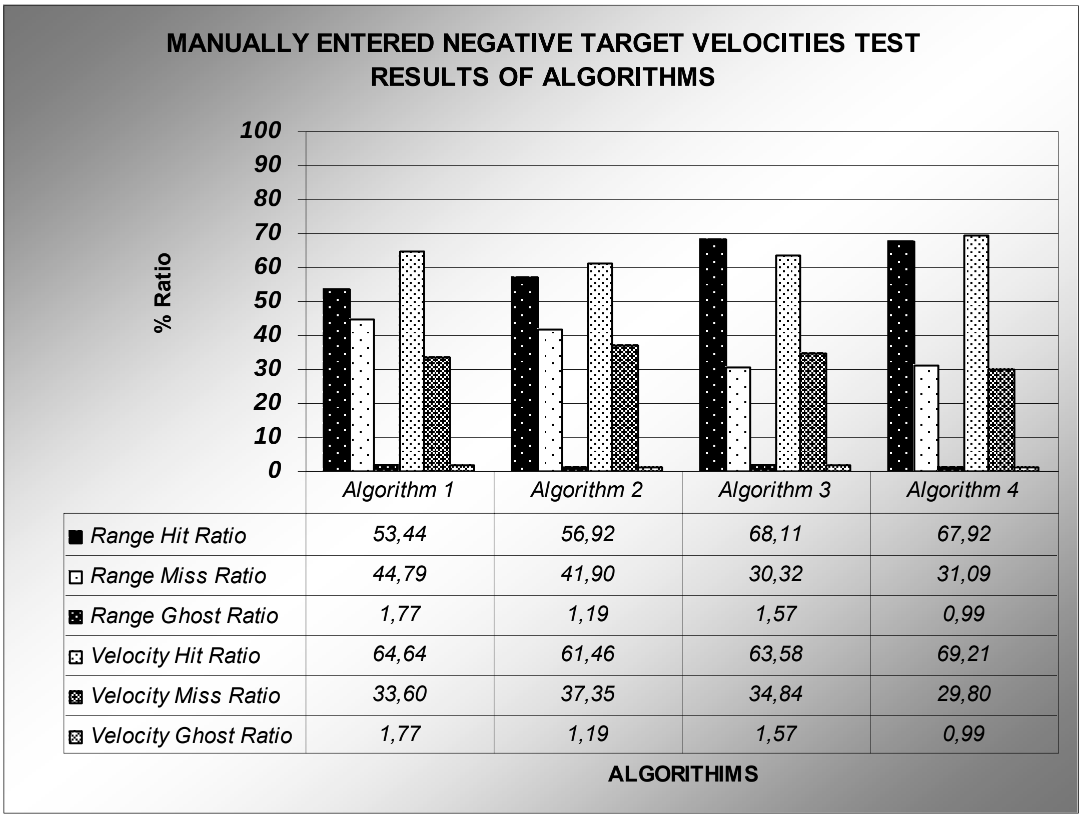
The system is tested for manually entered target velocities. This provides user to test the algorithms for specific target velocities. The tests are done by using 5 targets having positive velocities 50 m/sec, 100 m/sec, 200 m/sec, 300 m/sec, 350 m/sec. By using constant velocities the effects of other parameters can be observed. The test results of algorithms for different positive manually entered target velocities are given below:



	Algorithm 1	Algorithm 2	Algorithm 3	Algorithm 4
Range Hit Ratio	53,44	56,92	68,11	67,92
Range Miss Ratio	44,79	41,90	30,32	31,09
Range Ghost Ratio	1,77	1,19	1,57	0,99
Velocity Hit Ratio	64,64	61,46	63,58	69,21
Velocity Miss Ratio	33,60	37,35	34,84	29,80
Velocity Ghost Ratio	1,77	1,19	1,57	0,99

Figure 45 Manually Entered Positive Target Velocities Test Results of Algorithms

The system is tested for manually entered negative target velocities. This provides user to test the algorithms for specific target velocities. The tests are done by using 5 targets having negative velocities -50 m/sec, -100 m/sec, -200 m/sec, -300 m/sec, -350 m/sec. By using constant velocities the effects of other parameters can be observed. Also it is useful for checking the negative folding of the algorithms. The test results of algorithms for different negative manually entered target velocities are given below:



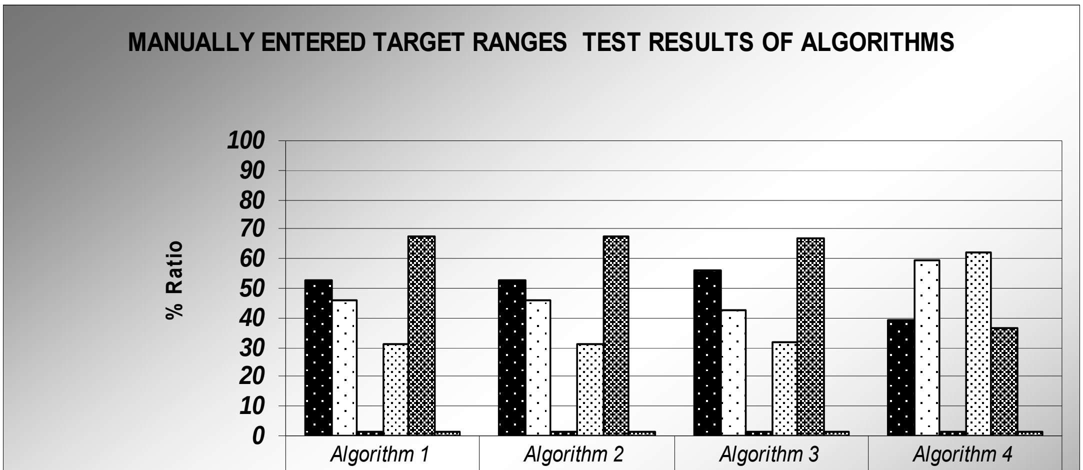
	Algorithm 1	Algorithm 2	Algorithm 3	Algorithm 4
Range Hit Ratio	53,44	56,92	68,11	67,92
Range Miss Ratio	44,79	41,90	30,32	31,09
Range Ghost Ratio	1,77	1,19	1,57	0,99
Velocity Hit Ratio	64,64	61,46	63,58	69,21
Velocity Miss Ratio	33,60	37,35	34,84	29,80
Velocity Ghost Ratio	1,77	1,19	1,57	0,99

Figure 46 Manually Entered Negative Target Velocities Test Results of Algorithms

According to the test results, it is seen that algorithm 4 has better performance for manually entered velocities. Their performances for negative and positive velocities are almost the same.

4.11 MANUALLY ENTERED TARGET RANGES TEST:

The system is tested for manually entered target ranges. The performances of algorithms can be observed better by using constant target ranges. Also it is useful for examination specific ranges. 5 targets with ranges 10.000 m, 20.000 m, 30.000 m, 40.000 m and 50.000 m are used for tests. The test results of algorithms for manually entered target ranges are given below:



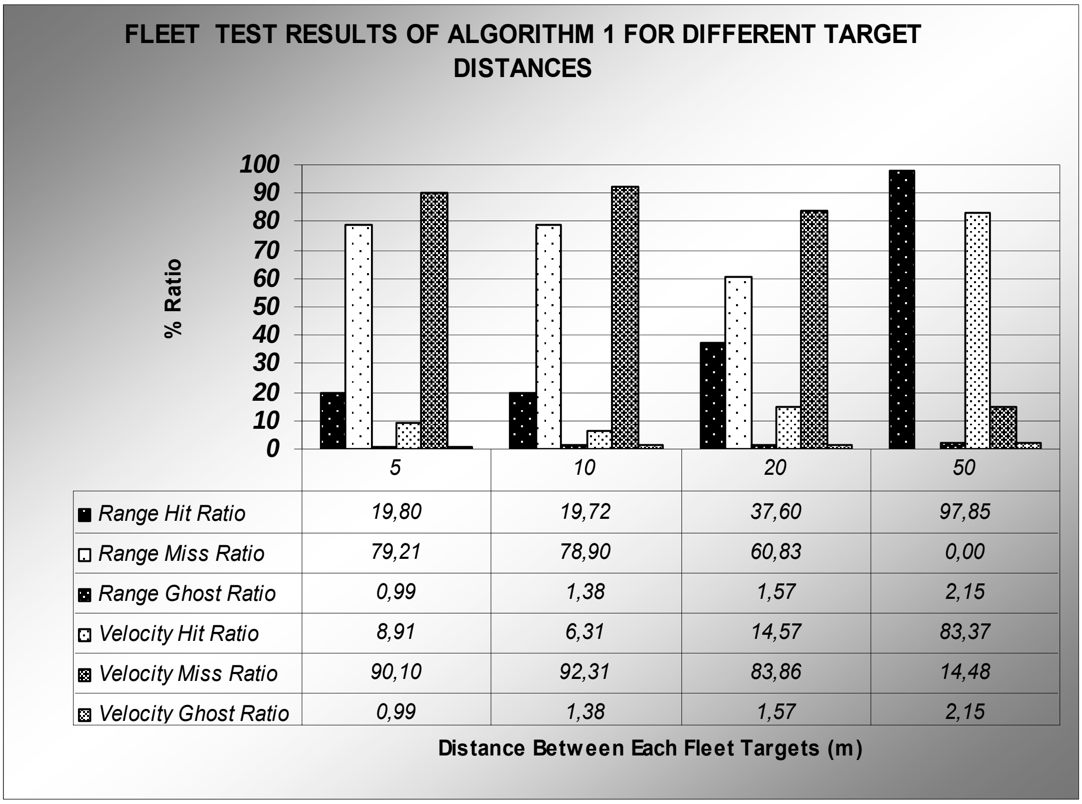
	Algorithm 1	Algorithm 2	Algorithm 3	Algorithm 4
Range Hit Ratio	52,66	52,66	56,21	39,53
Range Miss Ratio	45,96	45,96	42,41	59,29
Range Ghost Ratio	1,38	1,38	1,38	1,19
Velocity Hit Ratio	30,97	30,97	31,76	62,45
Velocity Miss Ratio	67,65	67,65	66,86	36,36
Velocity Ghost Ratio	1,38	1,38	1,38	1,19

Figure 47 Manually Entered Target Ranges Test Results of Algorithms

From the results, the range performance of algorithm 3 is better than the others. The last target with range 50.000 m has a small probability of detection. Because of this, it has a negative effect on performance.

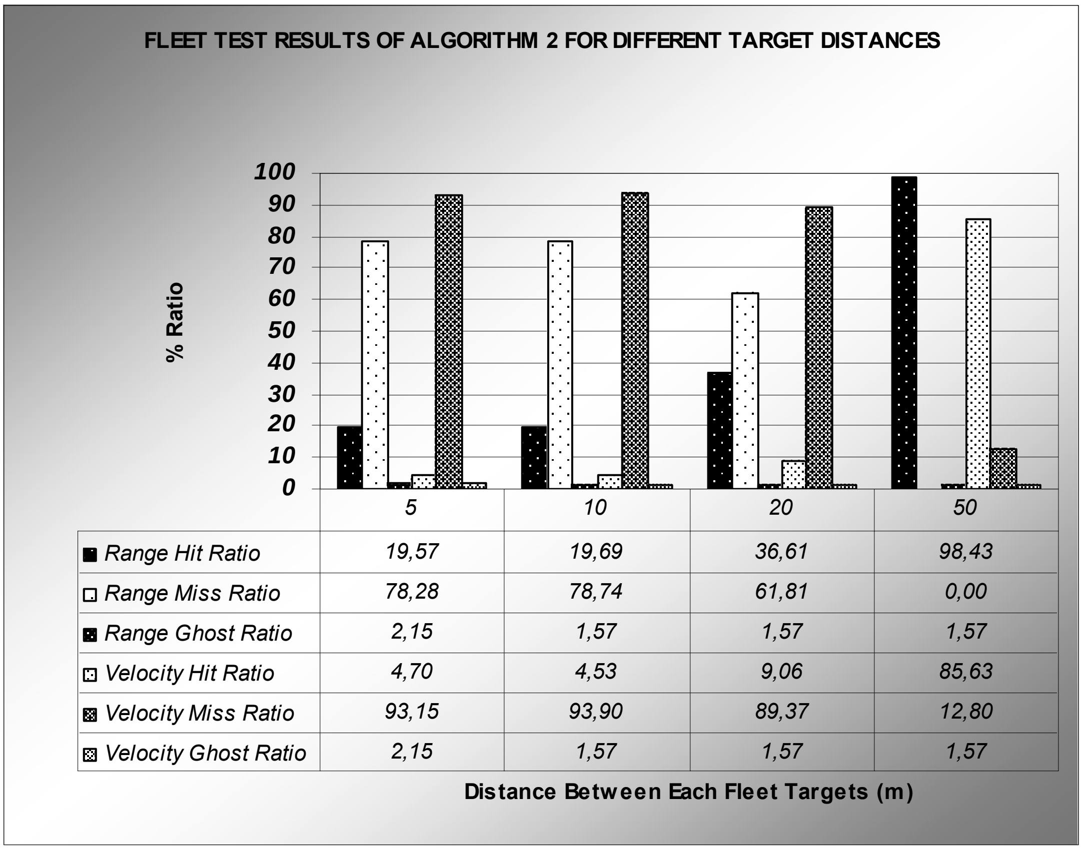
4.12 MANUALLY ENTERED FLEET TARGET RANGES TEST:

The system is tested for manually entered fleet target ranges.A fleet is a group of target that are moving close to each other. In a fleet, the targets may be observed as a single target due to their distance and due to the resolution of system and algorithm. The performances of algorithms can be observed better by using close fleet target ranges. Also it is useful for examination specific ranges and resolution ability of algorithms for closely located fleet targets. The tests are done by using a fleet of 5 targets that the first target is located at distance 30.000 m. The others are located at 2 m apart from one after another. The tests are also done for targets located apart from each other for distances 5 m, 10 m, 20 m, 50m . For closely located targets, it will be difficult to resolve the targets due to the length of resolution cell. For longer distances, the resolution will be better. The test results of algorithms for manually entered fleet target ranges are given below:



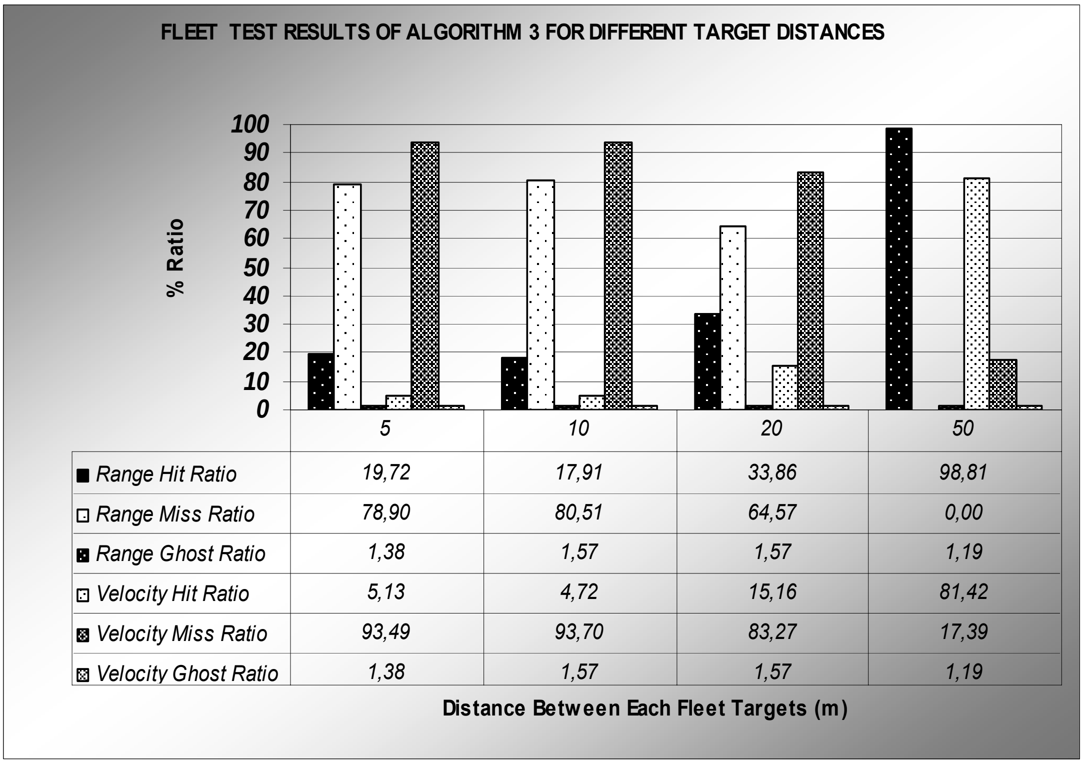
	5	10	20	50
Range Hit Ratio	19,80	19,72	37,60	97,85
Range Miss Ratio	79,21	78,90	60,83	0,00
Range Ghost Ratio	0,99	1,38	1,57	2,15
Velocity Hit Ratio	8,91	6,31	14,57	83,37
Velocity Miss Ratio	90,10	92,31	83,86	14,48
Velocity Ghost Ratio	0,99	1,38	1,57	2,15

Figure 48 Fleet Test Results of Algorithm 1For Different Target Distances



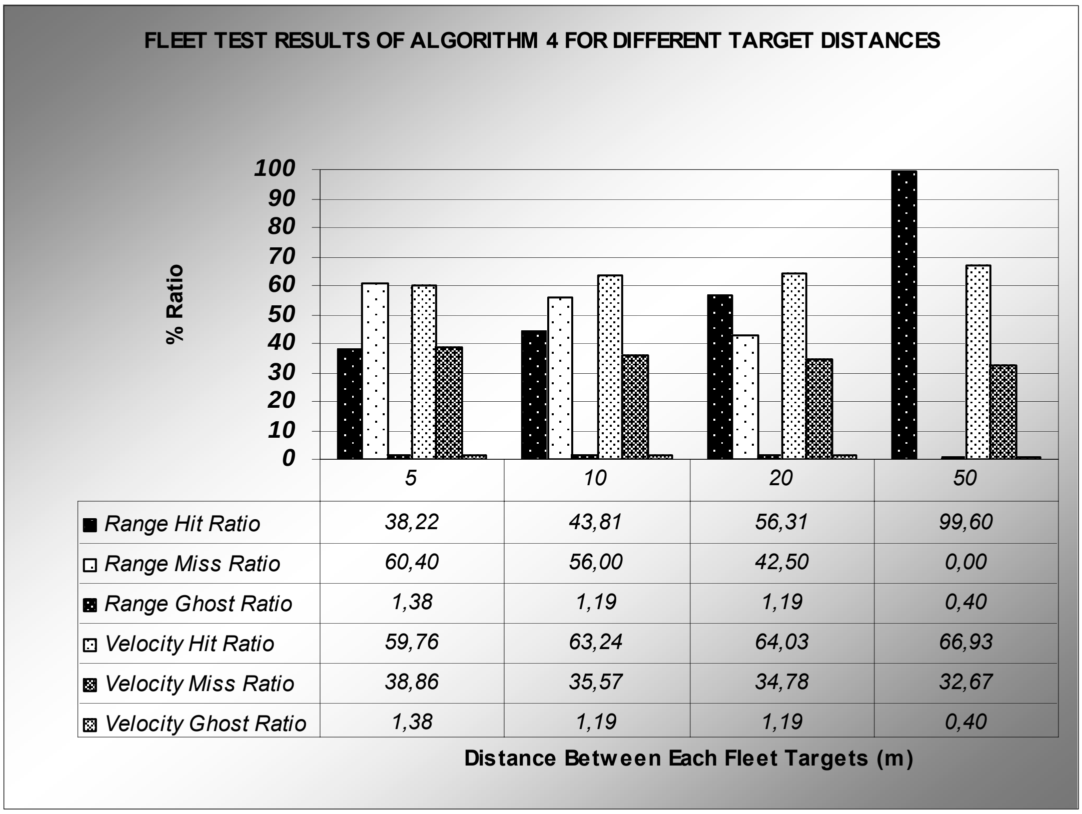
	5	10	20	50
Range Hit Ratio	19,57	19,69	36,61	98,43
Range Miss Ratio	78,28	78,74	61,81	0,00
Range Ghost Ratio	2,15	1,57	1,57	1,57
Velocity Hit Ratio	4,70	4,53	9,06	85,63
Velocity Miss Ratio	93,15	93,90	89,37	12,80
Velocity Ghost Ratio	2,15	1,57	1,57	1,57

Figure 49 Fleet Test Results of Algorithm 2For Different Target Distances



	5	10	20	50
Range Hit Ratio	19,72	17,91	33,86	98,81
Range Miss Ratio	78,90	80,51	64,57	0,00
Range Ghost Ratio	1,38	1,57	1,57	1,19
Velocity Hit Ratio	5,13	4,72	15,16	81,42
Velocity Miss Ratio	93,49	93,70	83,27	17,39
Velocity Ghost Ratio	1,38	1,57	1,57	1,19

Figure 50 Fleet Test Results of Algorithm 3For Different Target Distances



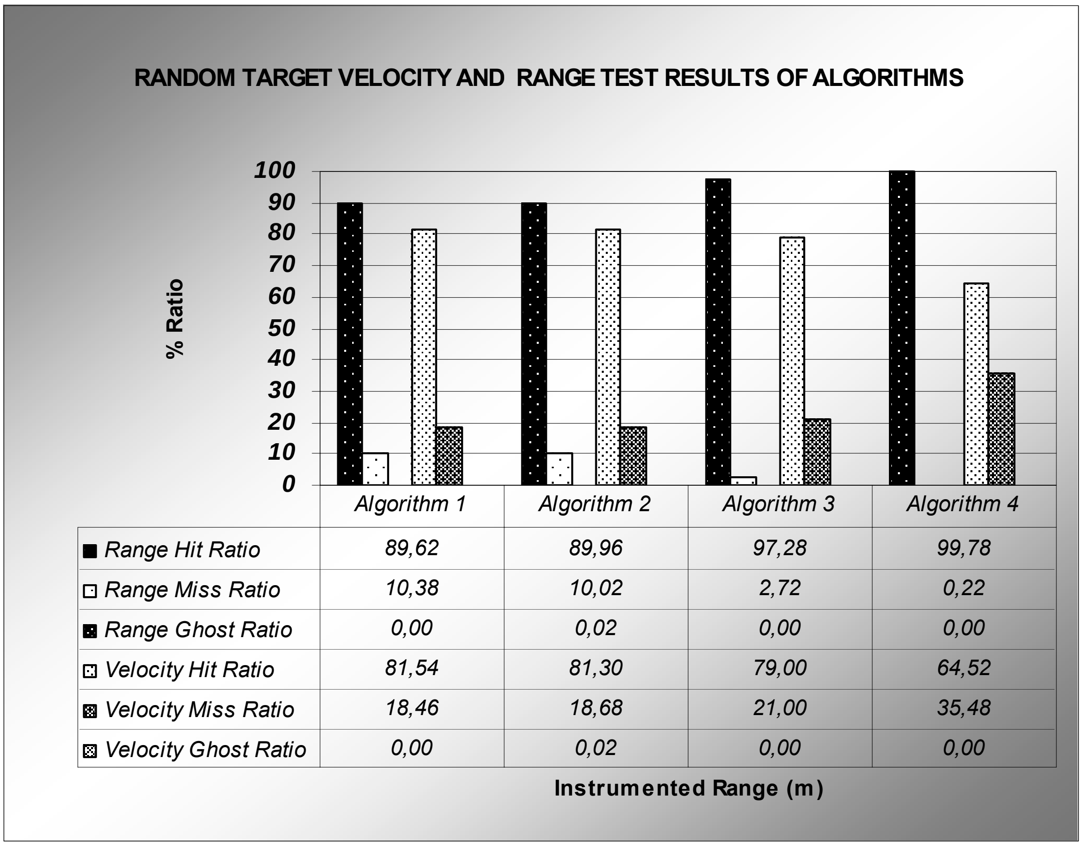
	5	10	20	50
Range Hit Ratio	38,22	43,81	56,31	99,60
Range Miss Ratio	60,40	56,00	42,50	0,00
Range Ghost Ratio	1,38	1,19	1,19	0,40
Velocity Hit Ratio	59,76	63,24	64,03	66,93
Velocity Miss Ratio	38,86	35,57	34,78	32,67
Velocity Ghost Ratio	1,38	1,19	1,19	0,40

Figure 51 Fleet Test Results of Algorithm 4For Different Target Distances

From the graphs, it is observed that, the targets that are located more than 20 m apart will be detected better. 20 meter means 2 in range bin unit. ±2 bins is a small value in calculations. If higher range resolution is required, one may use higher PRI values and change the operating frequency of the system. The length of the resolution cell should also be changed with respect o these modifications. It is clear that the algorithms are more effective for targets located apart more than 20 meters.

4.13 RANDOM TARGET RANGES AND VELOCITIES TEST:

The system is tested for randomly created target ranges and target velocities for observing the real performances of algorithms. All the parameters are entered due to the previously created scenario. The algorithms are tested for 1000 times for stable results. The test results of algorithms for manually for randomly created target ranges and target velocities are given below:



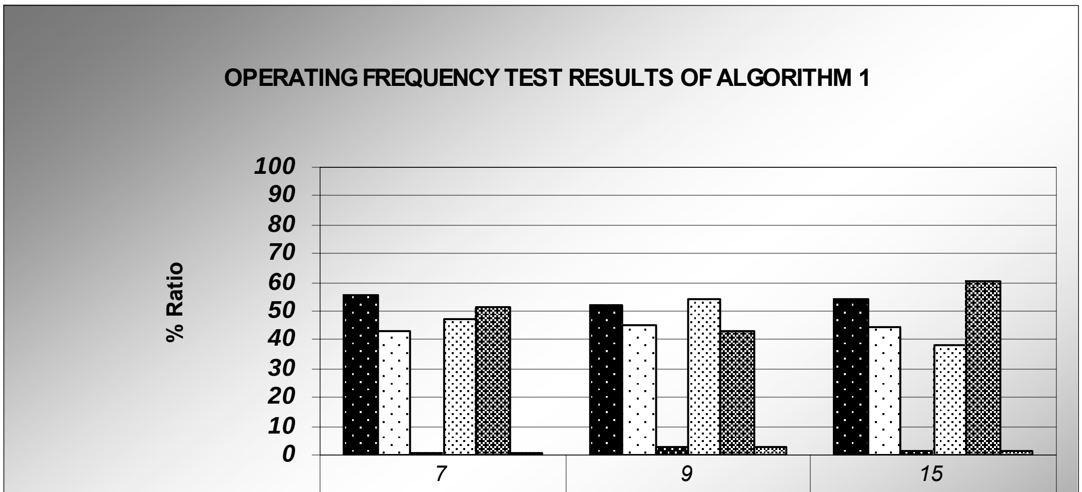
	Algorithm 1	Algorithm 2	Algorithm 3	Algorithm 4
Range Hit Ratio	89,62	89,96	97,28	99,78
Range Miss Ratio	10,38	10,02	2,72	0,22
Range Ghost Ratio	0,00	0,02	0,00	0,00
Velocity Hit Ratio	81,54	81,30	79,00	64,52
Velocity Miss Ratio	18,46	18,68	21,00	35,48
Velocity Ghost Ratio	0,00	0,02	0,00	0,00

Figure 52 Random Target Velocity and Range Test Results of Algorithms

It is seen that Algorithm 4 is superior in range detection but it does not have good performance for velocity detection. After this algorithm, the Algorithm 3 has the second good performance for range detection. It cam be said that Algorithm 3 is the optimum algorithm for application.

4.14 OPERATING FREQUENCY TESTS:

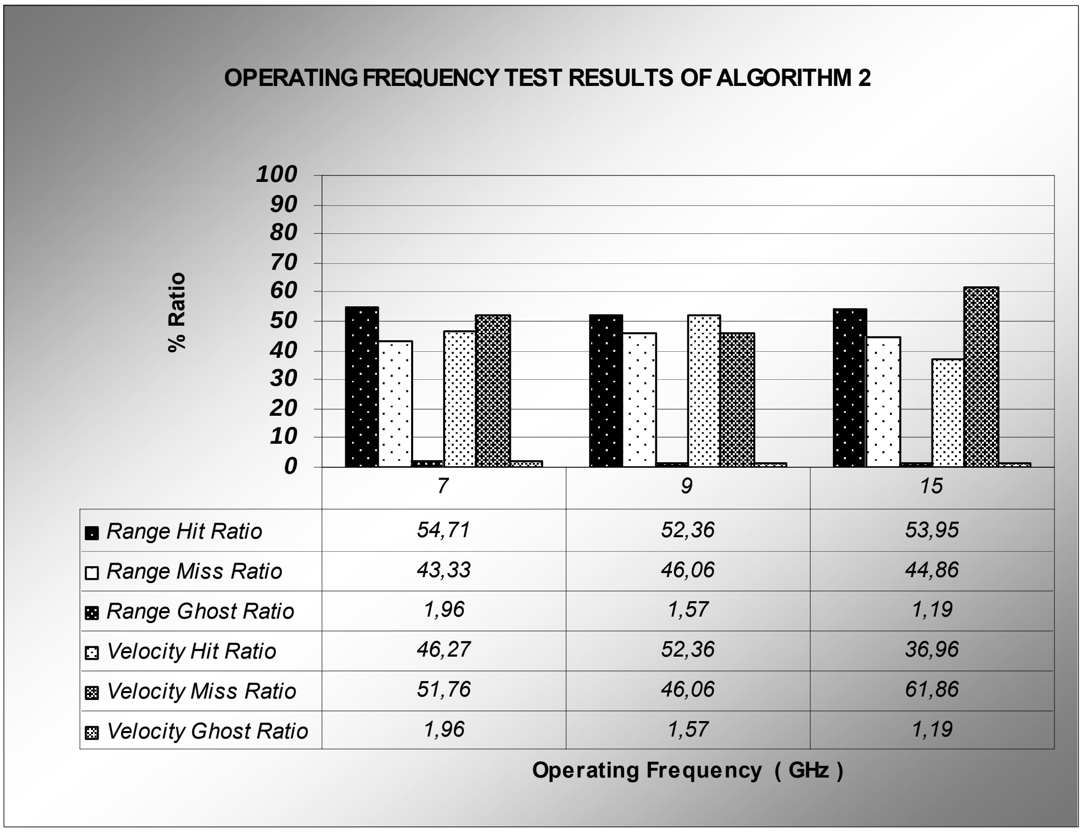
The algorithms are tested for 5 GHz, 7 GHz and 15 GHz operating frequencies. The wavelength of operation is equal to formula (7) . The relation between unambiguous velocity for a PRI and wavelength is given by formula(10). Increasing the frequency decreases the wavelength. Small wavelength reduces the maximum unambiguous velocity. The received velocity is in folded state and it is distributed in Doppler bins. The small unambiguous velocity reduces the detection sensitivity. Because of these reasons, for higher frequencies, the velocity performance of a PRI is reducing. For eliminating this smaller PRI values should be used but in this case it reduces the range detections. Because of band width relations, the PRI values should remain unchanged for both range and velocity detections.



	7	9	15
Range Hit Ratio	55,64	51,95	54,13
Range Miss Ratio	43,37	45,33	44,29
Range Ghost Ratio	0,99	2,72	1,57
Velocity Hit Ratio	47,33	54,09	38,19
Velocity Miss Ratio	51,68	43,19	60,24
Velocity Ghost Ratio	0,99	2,72	1,57

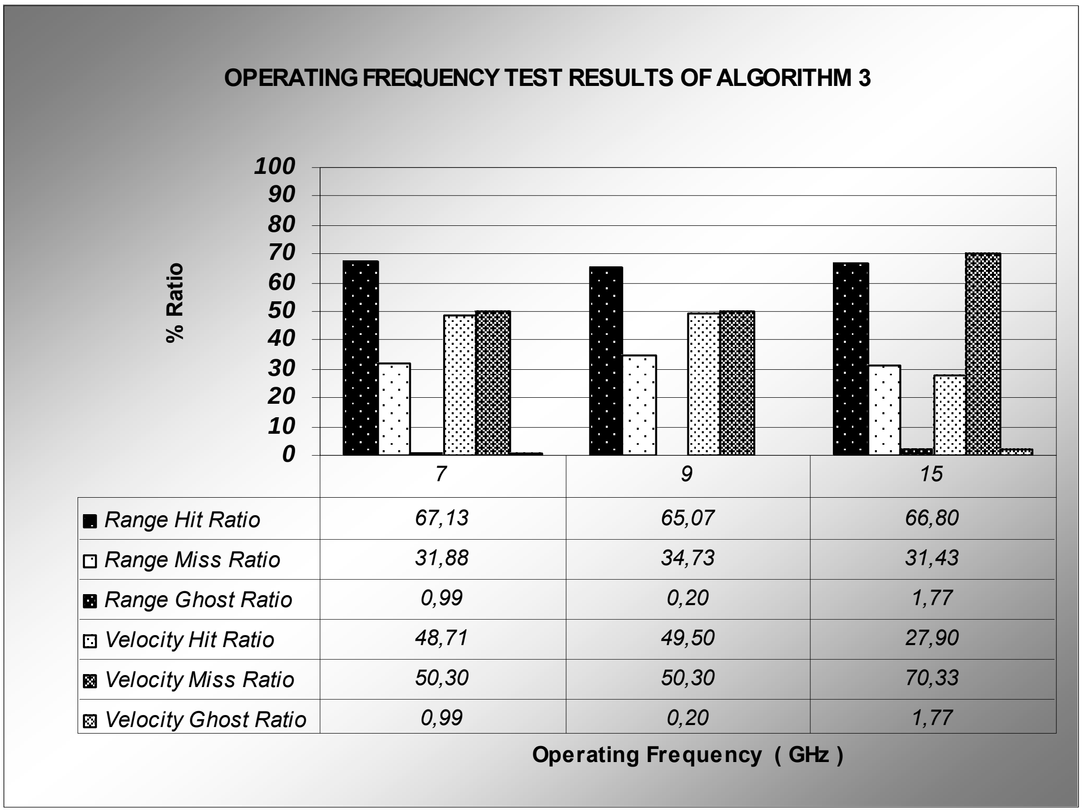
Operating Frequency (GHz)

Figure 53 Operating Frequency Test Results of Algorithm 1



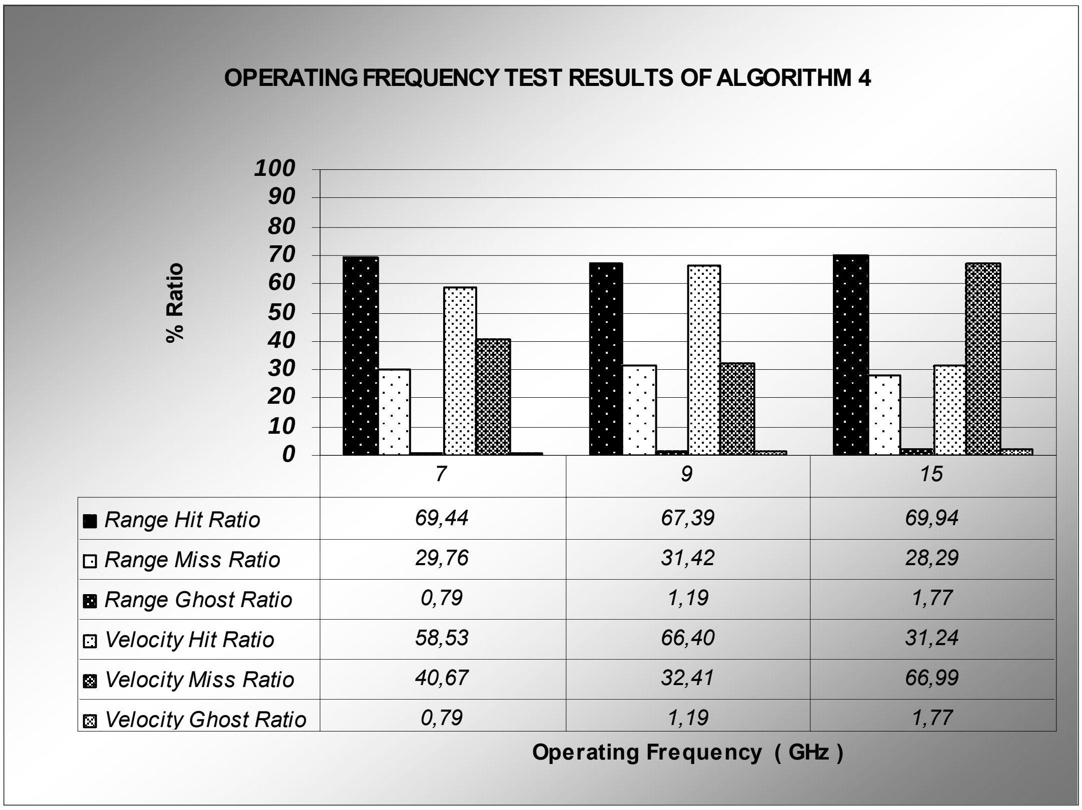
	7	9	15
Range Hit Ratio	54,71	52,36	53,95
Range Miss Ratio	43,33	46,06	44,86
Range Ghost Ratio	1,96	1,57	1,19
Velocity Hit Ratio	46,27	52,36	36,96
Velocity Miss Ratio	51,76	46,06	61,86
Velocity Ghost Ratio	1,96	1,57	1,19

Figure 54 Operating Frequency Test Results of Algorithm 2



	7	9	15
Range Hit Ratio	67,13	65,07	66,80
Range Miss Ratio	31,88	34,73	31,43
Range Ghost Ratio	0,99	0,20	1,77
Velocity Hit Ratio	48,71	49,50	27,90
Velocity Miss Ratio	50,30	50,30	70,33
Velocity Ghost Ratio	0,99	0,20	1,77

Figure 55 Operating Frequency Test Results of Algorithm 3



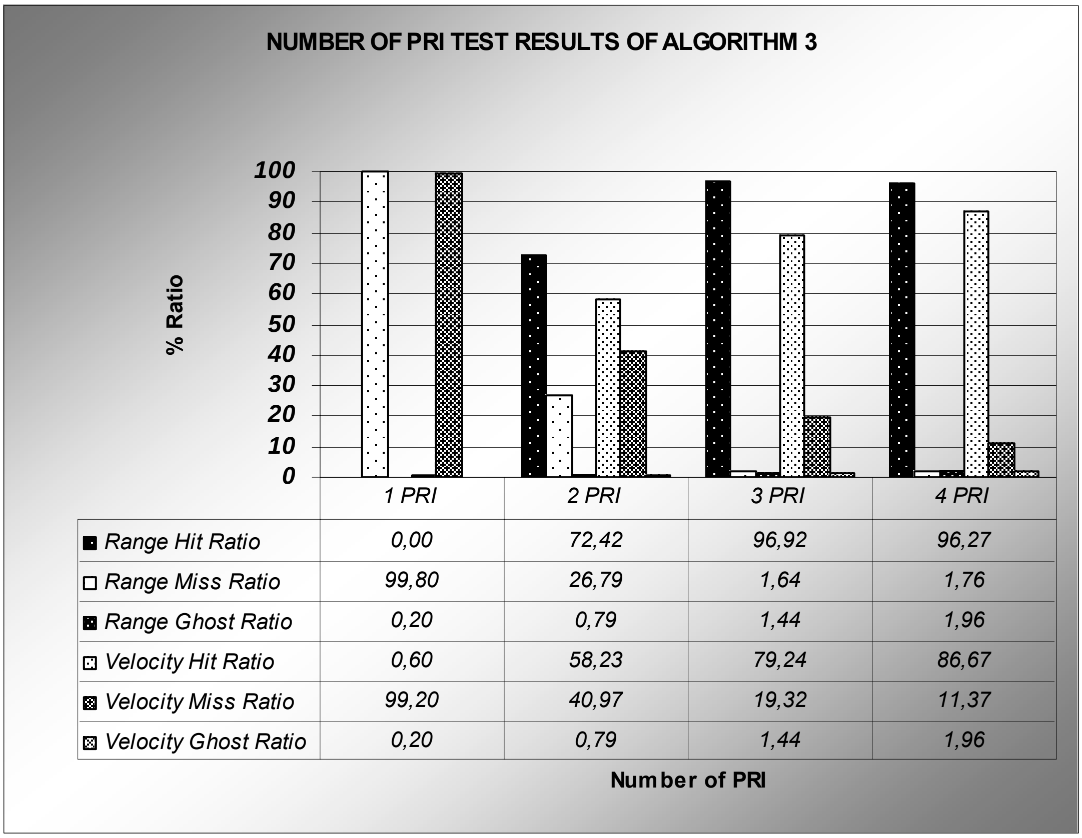
	7	9	15
Range Hit Ratio	69,44	67,39	69,94
Range Miss Ratio	29,76	31,42	28,29
Range Ghost Ratio	0,79	1,19	1,77
Velocity Hit Ratio	58,53	66,40	31,24
Velocity Miss Ratio	40,67	32,41	66,99
Velocity Ghost Ratio	0,79	1,19	1,77

Figure 56 Operating Frequency Test Results of Algorithm 4

According to the results, the 5 GHz and 7 GHz are usable frequencies. But among the three frequencies, 7 GHz is optimum for operation. For high frequency, it is seen that there is a serious decrease on velocity performances of all algorithms. The range performances remained almost the same for all algorithms.

4.15 NUMBER OF PRIS TEST :

The system is tested for different number of PRIs. The PRI set is 100 µsec, 130 µsec, 160 µsec, 185 µsec. Instrumented range is taken as 40 km for preventing the probability of detection loses. For single PRI it is not certain how many times the range is folded from. Also it is not certain how many times the velocity is folded. So we need at least 2 PRI for certainty. Sometimes the velocity may be folded into the zero Doppler bin or the velocity may correspond to a blind velocity for the used PRI. The range detections may also correspond to a blind range. There may be some loose on received signals. For these situations two PRI can be not satisfying. For that reason an additional third PRI is required. Using more PRI gives more accurate and better results. The test results of algorithms for two and three PRIs are given below:



	1 PRI	2 PRI	3 PRI	4 PRI
Range Hit Ratio	0,00	72,42	96,92	96,27
Range Miss Ratio	99,80	26,79	1,64	1,76
Range Ghost Ratio	0,20	0,79	1,44	1,96
Velocity Hit Ratio	0,60	58,23	79,24	86,67
Velocity Miss Ratio	99,20	40,97	19,32	11,37
Velocity Ghost Ratio	0,20	0,79	1,44	1,96

Figure 57 Number of PRI Test Results of Algorithm 3

In the single PRI, there is almost none detections. For 2 PRI there range and velocity detections. For 3 PRI both range and velocity performances are improved. For the 4 PRI, only velocity improvement is observed. So for detection, we need at least 2 PRI. For better performance a 3'th PRI will be useful.

4.16 SCANNING TEST:

The system is also tested under a 3-D scanning. The system can be a rotating antenna or phase array antenna.The targets are created and distributed in 3 dimensions randomly and their positions are defined by using vertical angle, horizontal angle and range. The vertical angle varies between 0° to 90° and the horizontal angle varies between 0° to 360°. The distance varies between 0 meters to instrumented range and the velocity is also produced randomly between negative maximum detectable velocities to positive maximum detectable velocity

.

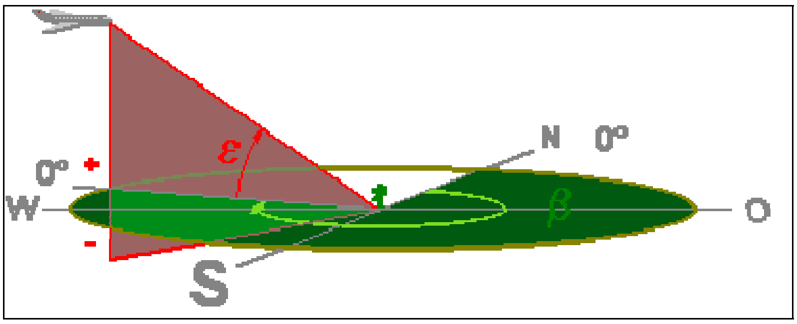


Figure 58 Target Creation in 3 Dimensions

The scanning is done by accepting the whole field as a matrix that has the dimensions [Number of Vertical Scanning, Number of Horizontal Scanning] .Each matrix element is accepted as a cell and the radar antenna beam is radiating only in that cell and the mid point of the beam is also centered in the mid point of the cell so that maximum energy is observed in the middle of the cell. The energy variation of the beam is accepted as Gaussian distribution in both vertical and horizontal direction. The beam shape is also considered as a fan beam and the vertical opening angle of the beam is assigned as 17° and the horizontal opening is assigned as 7°.

The antenna pattern selection is done arbitrarily so one may try some other patterns or opening angle values. The beam shape for the used system is given below:

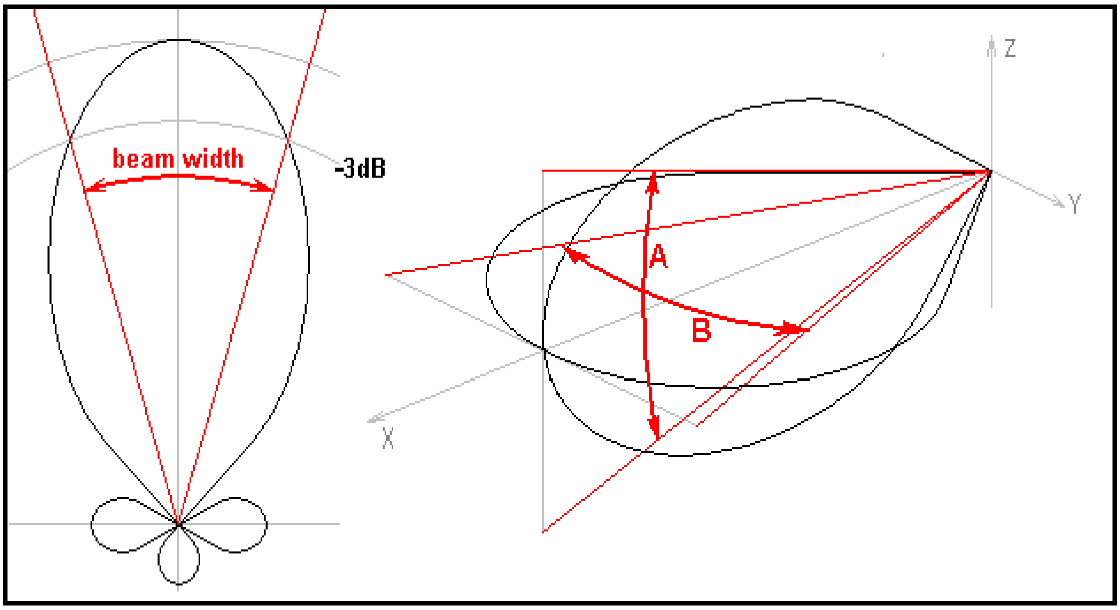


Figure 59 Main Lobe Pattern of Fan Beam

The scanning system can be a rotating antenna or phase array antenna. Phased-array antennas offer the advantage that the beam may be electronically scanned almost instantly. This allows search, tracking and other radar functions to be interlaced, and many targets to be observed near-simultaneously. Radar that employ phased arrays often have a large repertoire of waveforms, and operate under computer control. [4]

The number of vertical scanning is assigned as 6 and the number of horizontal scanning is assigned as 180.So the procedure is done 6x180 times for one cycle of scanning. The scanned field can be considered as a matrix like [Number of Vertical Scanning, Number of Horizontal Scanning]. If the rows are called as “ii” and columns are called as “jj”, then every processed cell can be addressed as (ii, jj) ‘th element of scanned matrix.

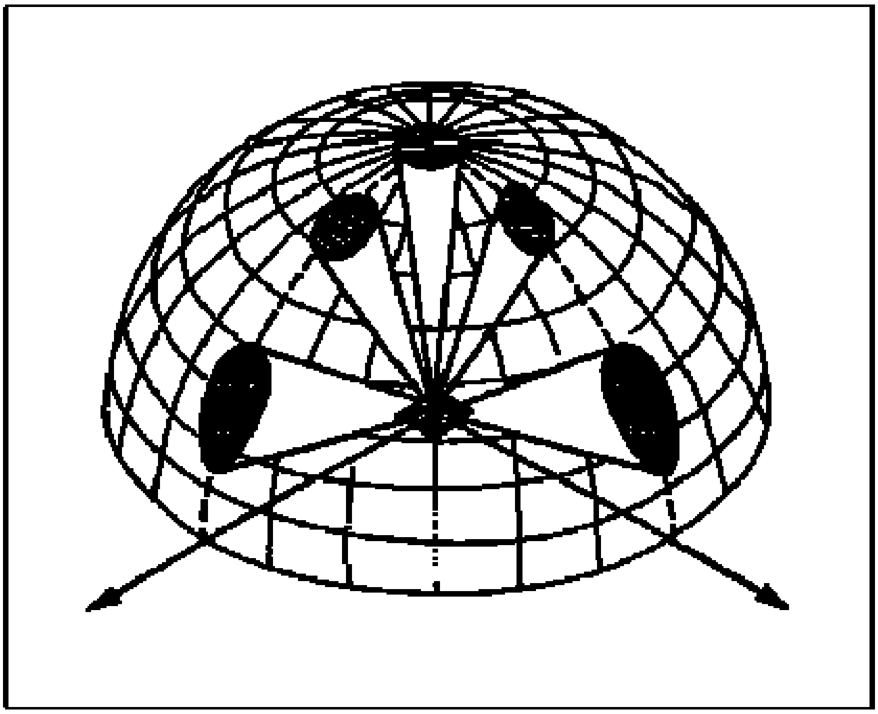


Figure 60 Scanning in 3 Dimensions

The scanning starts from the home position where the cell address is ii=1 and jj=1. Then it goes on scanning to upwards through that column till the top element of the column. The scanned elements order for a column can be addressed as (ii, jj), (ii, jj+1), (ii, jj +2), (ii, jj +3), (ii, jj +4), (ii, jj +5). After finishing a column, the antenna beam goes to the lower position in the next column and starts scanning from this cell till the top cell of this new column. The scanned elements order for the next column can be addressed as (ii+1, jj), (ii+1, jj+1), (ii+1, jj +2), (ii+1, jj +3), (ii+1, jj +4), (ii+1, jj +5) .

The scanning direction starts from 0° to 90° in vertical direction and starts from 0° to 360° in horizontal direction. The cell distribution and scanning direction is given in the below figure:

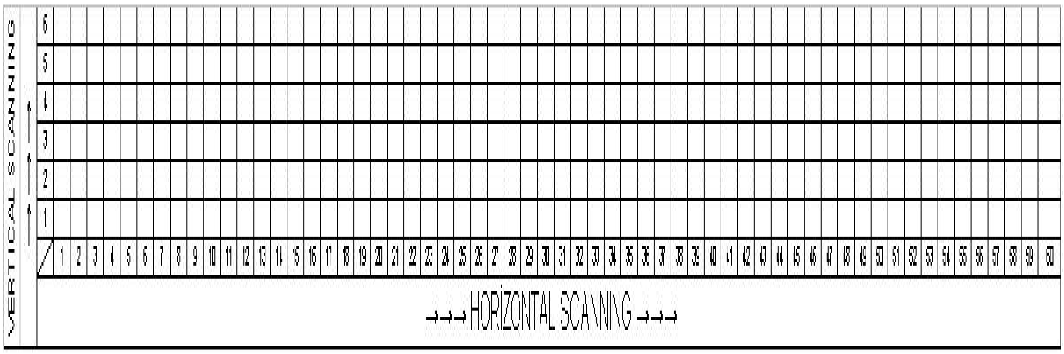


Figure 61 Scanned Cells and Scanning Direction

The scanning is tested for the algorithm 3. The procedure starts first creating the actual targets. After this the scanning starts from the first cell. In real applications, the system uses different PRI's due to the requirements of detections. One, two, three or more than three PRI's may be used by the deciding or tracking algorithms. For simulating this, the used PRI's altered randomly. In one cell PRI 2, in the next one PRI 1, 3, in the other one PRI 2, 3, in the next one PRI 1, 2, 3 may be used. So, every cell may have different or the same signal information due to the PRI altering.

Also in every cell and in the used PRI set of the cell, some false targets may be added as received signals due to the probability of false alarms. This is also simulated in scanning. If a false target occurs, it is also added to the target list of that cell and it is also searched by the algorithm.

The other fact is the angular position of the target in the processed cell. As the beam energy distribution is Gaussian, the received energy from that target varies due to its position in the cell. The received energy amount is maximum in the middle of the cell and it decreases as the position goes to the sides of the cell. This effect is applied in both the vertical and horizontal position. The energy variation effects the probability of detection. Another effect on energy is the distance of target from the radar. The probability of detection is calculated with respect to the distance, angular position of targets. After determining the probability of detection, the system checks whether the system receives signal from that target or not due to this value.

After creating this, the simulator calls a subroutine “Search_Process.m”, This function creates a dataset that contains information from the observed cell, and the adjacent cells.

In scanning a cell, the system only has information from the scanned cell, with respect to the scanning direction. The decision mechanism uses a synthesis of datas from both adjacent cells and observed cell. In this model, the information is extracted from the cells as given below:

Observed Information	Observed Information	No Information	No Information	No Information	No Information
Observed Information	Adjacent Cell (ii+1, jj-1)	No Information	No Information	No Information	No Information
Observed Information	Adjacent Cell (ii, jj-1)	Observed Cell (ii, jj)	No Information	No Information	No Information
Observed Information	Adjacent Cell (ii-1, jj -1)	Adjacent Cell (ii-1, jj)	No Information	No Information	No Information
Observed Information	Observed Information	Observed Information	No Information	No Information	No Information

Figure 62 Observed Cell, Adjacent Cells and The Data State of Other Cells

The Search_Process. returns the dataset that contains data from the observed cell (ii, jj), adjacent cell (ii+1, jj-1), adjacent cell (ii, jj-1), adjacent cell (ii-1, jj -1), adjacent cell (ii-1, jj). This dataset is sent to the algorithm as data input.

The system creates hit datas in case of detection in a processed cell and usually the same results are observed in the processing of adjacent cells. Producing result should be done just at same time of occurrence because there is time limitation in real operation. If a target is detected, the decision mechanism may want to focus on that target just at that time.
The results show that the larger beam width with respect to the angular width of the cell provides more observation signal for decision. The projection is as shown in the figure.

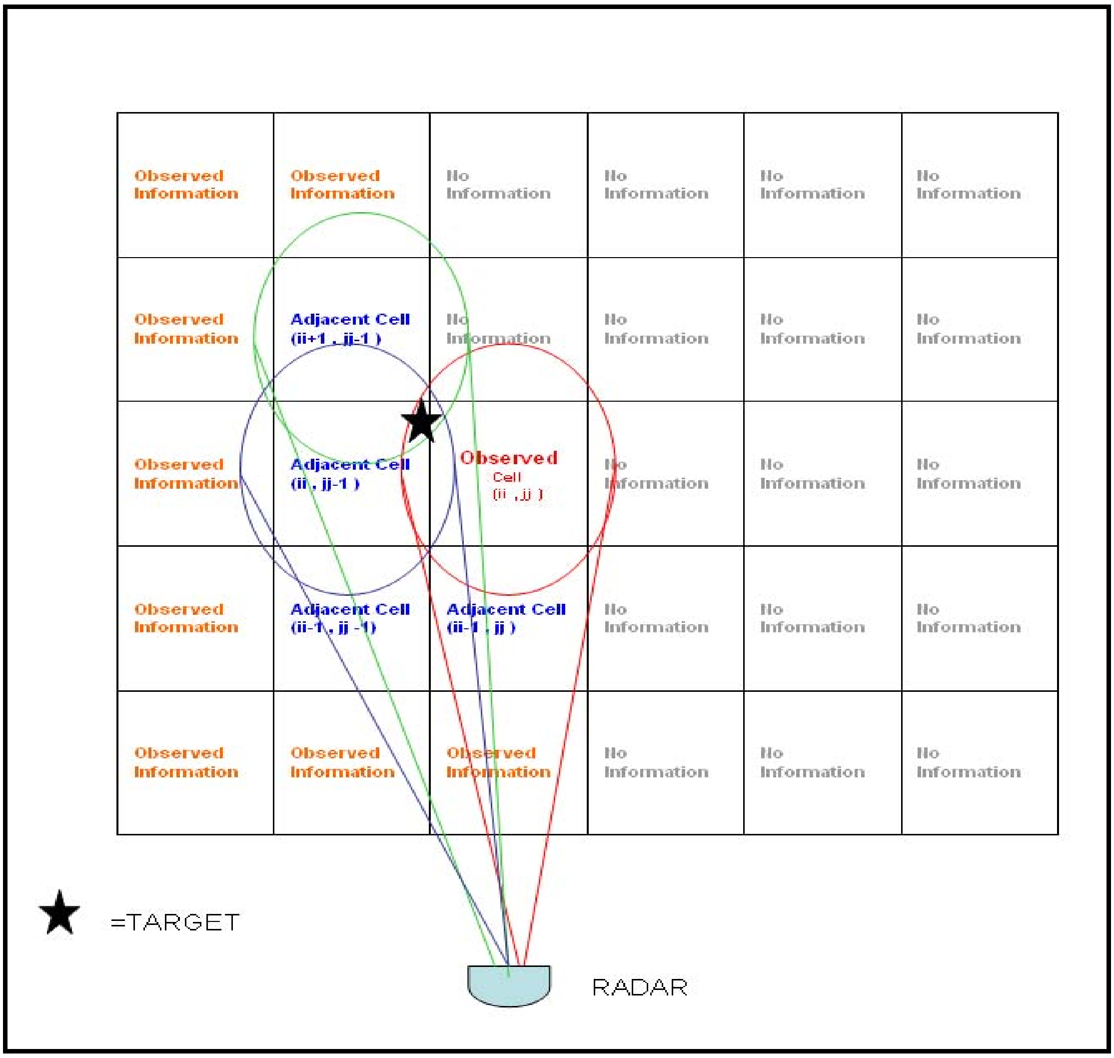


Figure 63 Beam Projections of Adjacent Scans On a Target

A target may occur in adjacent cells because the projection of the beam is larger than the projected cells borders. When all these detections from adjacent cells are collected, the probability of detection of a target by the used algorithm is increased.

There is a disadvantage of this multi occurrence. The target is detected in the close hits and reported by the algorithm, the system can not be sure about the certain location of the target. So a secondary decision mechanism is required for detecting the exact location of the target from the detected cells. But for an exact detection the algorithms needs all the results of detected cells. It is not possible because in the first cell that the target occurs, the system has no information of the next cells to be scanned. This can be done by tracking algorithms and this is out of the scope of this study.

5.CONCLUSIONS

In this study 4 different algorithms and different methods of velocity and range detection are tested. As it is mentioned before, the numerical performances of algorithms are at reasonable levels. But in the tests with the other parameters, the performances are decreased.

The main parameter in data loss is the difference between instrumented range and minimum detectable range. The targets are created randomly between 0 to instrumented range. As the difference gets bigger, the probability of a targets range being in an invisible range gets higher. For targets located beyond the minimum detectable range, the probability of detection decays quickly by the distance. This causes a data loss because due to simulation, the data received from that target for the used PRI will be ignored. In this study, the probability of detection is calculated by a rough approximation. For a real test clutter, target characteristics, transmitted signal type, terrain map,receiver type etc.... are required [22].[In a real test, the probability of detection of the terrain should be provided.

Another fact causing data loss is the blind range. From the results, it is seen that the performance of the algorithms are reduced by the increasing length of blind range. The targets corresponding to this zone are ignored by the system. In actual operations, this is a necessity because this region contains great amount of clutter. But for getting better performance, a shorter blind zone range should be provided.

Another factor is the probability of false alarms. If the false alarm level is high, the system may receive many false signals and these signals cause conflicts in algorithms. Some of them may make some combinations with real signals and they cause false decisions. It is observed that as the performances of the all algorithms are reduced by the increment of probability of false alarms.

The increment of the PRI bin number did not give better velocity results as expected. This can be caused by data losses or the used PRI set is not suitable for such an application.

In the length of resolution cell test, it is observed that 10 is an optimum value. For 5 m and 10 m, the performances are almost the same. For 20 meters, the range performance decrease rapidly. However the algorithms produce close results to actual ranges in bins unit, they are very different when they are converted into meter unit. For example a 2 bin difference means 40 m in range. The value of range resolution bin is also related to the used PRI set used operating frequency.

The other test parameter is the maximum detectable velocity. From the results, it is seen that the velocity detection performances decrease by the increment of maximum detectable value. The received Doppler is a folded value. It is folded by the maximum detectable velocity of the used PRI. For higher speeds, the velocity is folded many times and the chance of finding the same value after unfolding is lessened. Also, for higher speeds, high PRF values should be used but it causes negative effect on range performance.

The algorithms are tested also tested for operating frequencies. Due to the formula (10), increasing the frequency decreases the wavelength and small wavelength reduces the maximum unambiguous velocity. The small unambiguous velocity reduces the detection sensitivity. Because of these reasons, for 15 GHz, a poor velocity performance is observed. There is a negligible variation in the range performances of all algorithms for all frequencies. It is seen that 7GHz is optimum for operation.

The algorithms are tested for positive and negative velocities for controlling the negative and positive folding and Doppler bin assignment. The performances are almost the same.

The other test is constant target ranges test. The performances get better for constant range because the location of targets were always at the same place. In random target creation, most of the targets may be invisible due to the low probability of detection, which is caused by far range location. The results can be better if all the target ranges are assigned between blind range and minimum detectable range.

The algorithms are tested for number of runs and it is observed that 100 runs give stable results and it is suitable for tests. Most of the tests are done by using 100 runs.

For range calculations, there are 3 different approaches tested. In the first three algorithms, The received signal from the targets is assumed to be in a mixed order for a PRI. They are first ordered and then processed.
For algorithm 1, only the highest PRI values unambiguous ranges are searched in the other PRI's unambiguous ranges. The highest PRI is the better PRI among the all PRI set because the higher PRI causes higher range unambiguity. It is seen that this methods performance is almost the same with searching all the each unambiguous ranges in the other unambiguous ranges of PRIs. This provides low calculation steps and higher speed.

In the second algorithm, the same procedure is used for range detections and the same things are valid for this algorithm.

In the third algorithm, all the unambiguous ranges of a target for each PRIs are collected in an array and sorted. Each element is subtracted from the next element for detecting the close hits. Close ones are assigned as the possible hits and collected in a new array. The same procedure is repeated and closest unambiguous ranges are assigned as final hit. This algorithm is more simple and rapid than the others. There is not so much calculations and sub functions.

In the fourth algorithm, the targets are not sorted for each PRI. All the received signals are unfolded and collected in an array. The pair combinations of PRIs are created and each PRIs unfolded elements are searched in the other PRIs unfolded elements. They got a merit value as search results and the ones with highest merits are assigned as final hit. This algorithm requires many calculation steps and not so much effective as the other algorithms.

For velocity calculations, 4 different approaches tested. In the first three algorithms, The received signal from the targets is assumed to be in a mixed order for a PRI. They are first ordered and then processed.
For algorithm 1, pair combinations of PRI set is created and the unfolded velocities of a target for one of the PRI is searched in the other unfolded velocities of the same target for the other PRI due to the combinations. By combination, each PRI result is searched in the other PRI results. The searches give a merit to the hit and the hits with highest merit are assigned as final velocity hit. It is effective in velocity detection.

In the second algorithm, all the unambiguous velocities of a target for each PRIs are collected in an array and sorted. Each element is subtracted from the next element for detecting the close hits. Close ones are assigned as the possible hits and collected in a new array. The same procedure is repeated and closest unambiguous velocities are assigned as final velocity hit. This algorithm is more simple and rapid than the others. There are not so much calculations and sub functions.
In the third algorithm, the same procedure is used for velocity detection.

In the fourth algorithm, the targets are not sorted for each PRI. All the received signals are unfolded and collected in an array. The pair combinations of PRIs are created and each PRIs unfolded elements are searched in the other PRIs unfolded elements. Each unfolded velocity gets a merit value as search results and the ones with highest merits are assigned as final velocity hit. This algorithm requires many calculation steps and has a poor performance in velocity when compared to the other algorithms.

Algorithm 3 is superior to the other by its rapid calculation and optimum performance in range and Doppler, so it can be suggested tto use in an application.

The 3 dimension scanning is also simulated for testing the algorithm. The power distribution of antenna pattern is assumed to be Gaussian . The probability of detection of targets is calculated due to their range and their angular position in the scanned cell. It is observed that, the system receives more data for processing if the angle of the scanning beam is larger than the scanned cell .The received data of a scanned cell should be stored for combining its data with the next cells data. This is necessary for detection because more data provides more accurate decisions. The unscanned cells data should be cleared for preventing a data conflict.

The aim of this thesis is the creation of ambiguity resolution algorithms and determination of the performances for different system parameters. One may try different algorithms by using this system or use different steps for simulating the effects of the parameters in processes.

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APPENDICES

A.BASIC RADAR INFORMATIONS ON RADARS AND MPRF DOPPLER RADARS

RADAR

The radar principle is based on sending electromagnetic pulse into the environment an waiting on for receiving echo. For measuring the range the system utilizes the speed of light and it is obtained by the relation

$$Range = \frac{c \times \Delta t}{2} \quad (15)$$

, where Δt is the total time elapsed for 2 way trip of the pulse

PULSED RADARS:

Pulsed radars are using coherent transmitting and receiving modulated pulse trains and the range information is extracted from the observed time delay between transmitted and received pulses .the Doppler measurement is accurate if consecutive pulses are used and the range information is calculated by the formula (15),by the assumption that the range is not changing through the time period Δt

In a pulsed radar the waveforms are defined by the

- Carrier frequency that is selected according to the mission and the design of the system
- Pulse width where it depends on the bandwidth and that affects the range resolution
- Modulation
- Pulse repetition frequency or pulse repetition interval

Pulsed radars are designed by using the maximum radial velocity of expected targets and the radar wavelength λ by the relation:

$$f_r = 2 f_{d\max} = \frac{2 v_{r\max}}{\lambda} \quad (16)$$

, where f_{dmax} is the maximum expected target Doppler frequency, v_{rmax} is the maximum expected radial target velocity, and λ is the operating wavelength of radar system. The block diagram of a pulsed radar is given in the figure below [23]:

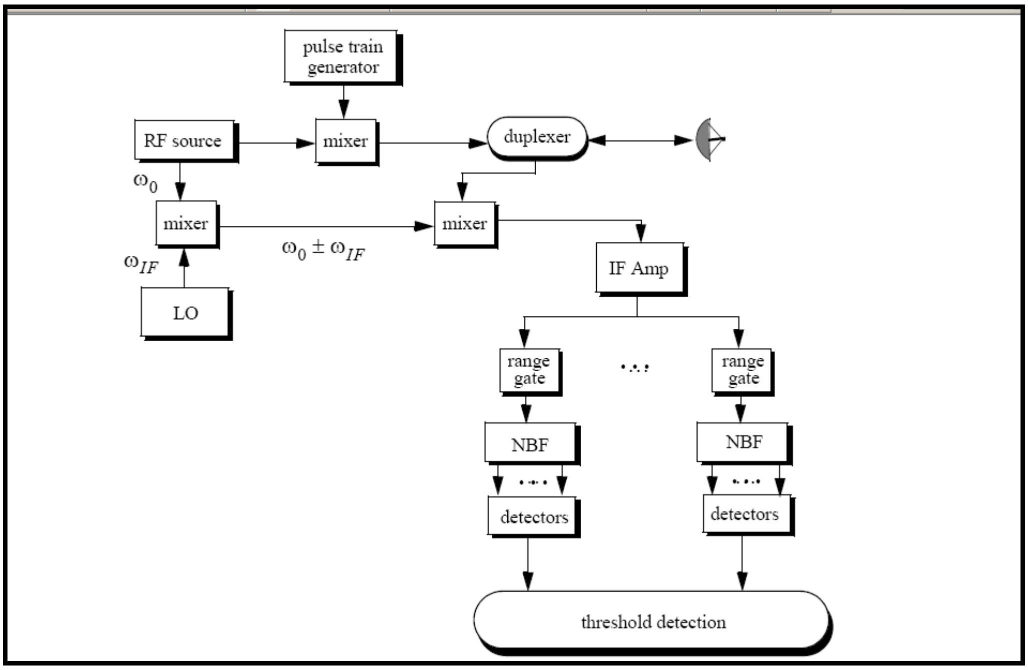

Figure 64 Pulsed Radar Block Diagram

PULSE REPETITION INTERVAL:

Pulse Repetition Interval (PRI) is the pulse repetition interval and in time unit generally expressed in milliseconds. The interval means the time period that is the period between the starting of one pulse and the starting of the next pulse. The total time is called transmission. The time period after sending the burst till the sending of next burst is called resting time (RT) so the system does not transmit any pulse. PRI = PW + RT = one second / # pulses per second

Pulse Repetition Interval (PRI) is the expression of PRF in1/time units. The relation between PRI and PRF is PRF =1/ PRI .

PULSE REPETITION FREQUENCY:

Pulse Repetition Frequency (PRF) is the number of transmitted pulses per second and generally in Hz or pps units.

Higher PRF provides more hits per cycle and higher detection probability but have the disadvantage of reduced range and ambiguity occurrence. So to overcome this multiple PRF systems are used.

DOPPLER SHIFT:

The frequency shift that occurs in electromagnetic and sound waves due to the motion of scatterer, targets that are closing or going away from the observer.

DOPPLER RADARS:

The radar type that has the ability of determining the frequency shift from the phase change measurement that occurs in electromagnetic waves through a pulses series are called as “Doppler Radars”. The Doppler radars are only sensitive to the radial motion of target objects.

The electric field component of a transmitted wave is given by:

$$E_t(t) = E_0 \cos(2\pi f_t t + \phi_0) \qquad (17)$$

Where ft is the transmitted frequency.

The returned electric field signal back to the radar receiver after a time interval Δt is:

$$E_t(t) = E_1 \cos(2\pi f_t (t + \Delta t) + \phi_1) \qquad (18)$$

The time interval is the period that takes two way time travel of the signal is equal to:

$$\Delta t = \frac{2r}{c} \quad (19)$$

After substituting the time period Δt into the above equation:

$$E_t(t) = E_1 \cos\left(2\pi f_t\left(t + \frac{2r}{c}\right) + \phi_1\right) \quad (20)$$

The received frequency can be found by taking the derivation and dividing by 2π. The result is the summation of transmitted and shifted frequency.

$$f_r = \frac{1}{2\pi}\frac{d}{dt}\left(2\pi f_t\left(t + \frac{2r}{c}\right) + \phi_1\right) = f_t + \frac{2f_t}{c}\frac{dr}{dt} = f_t + \frac{2f_t v_r}{c} = f_t + f_d \quad (21)$$

The Doppler radars must have highly stable transmitters and receivers because the frequency shifts are generally very small .Here are some sample results of Doppler shift magnitudes for different velocity and frequencies:[3]

Table 2 Doppler Shift Magnitudes For Different Velocities and Frequencies

	Transmitted Frequency		
	X band	*C band*	*S band*
Radial velocity	*9.37 GHz*	*5.62 GHz*	*3.0 GHz*
1 m/s	*62.5 Hz*	*37.5 Hz*	*20.0 Hz*
10 m/s	*625 Hz*	*375 Hz*	*200 Hz*
50 m/s	*3125 Hz*	*1876 Hz*	*1000 Hz*

The distance for a target that moves radially in a period T is equal to

$$d=T.v_r \qquad (22)$$

The phase shift for two consecutive pulses is equal to :

$$\left(\frac{\phi_2-\phi_1}{2\pi}\right)=\frac{2T_r v_r}{\lambda} \qquad (23)$$

Also the radial velocity of a target is equal to :

$$v_r=\frac{\lambda}{2T_r}\left(\frac{\phi_2-\phi_1}{2\pi}\right) \quad (24)$$

For determining a frequency shift we need at least two consecutive pulses. The phase shift should be smaller than a half of the wavelength. For ∆Ø=Ø2-Ø1, the radial velocity will be:

$$v_r=\frac{\lambda}{2T_r}\left(\frac{\Delta\phi}{2\pi}\right) \quad (25)$$

And the phase shift is

:

$$\left|\Delta\phi\right|=\left|\frac{4\pi v_r T_r}{\lambda}\right|<\pi \qquad (26)$$

So the maximum unambiguous velocity that can be detected and not folded will be:

$$\left|v_r\right|=\left|\frac{\lambda}{2T_r}\right|=\frac{\lambda f}{4}=v_{\max} \quad (27)$$

For a large unambiguous range,Doppler type radars must operate at a low PRF.

The maximum unambiguous range (Runamb) is the range that the target occurs as “second time around,” echo or arriving echo after the transmission of the next pulse. This is the maximum unambiguous actual range that can be detected.

$$R_{unamb} = \frac{c}{2}(PRI) \quad (28)$$

or can expressed by formula (1)

Minimum detectable range (R_{min}) is the smallest range that radar can first be able to detect a target object and given by:

$$R_{\min} = \frac{c}{2}(PW) \quad (29)$$

Another parameter is Range Resolution (R_{res}) is the ability of system to separate 2 close targets that are nearly the same range.

$$R_{res} = \frac{c}{2}\left(\frac{PW}{PCR}\right) \quad (30)$$

The maximum velocity is:

$$v_{\max} = \frac{\lambda \times PRF}{4} \quad (31)$$

So the multiplication of maximum velocity and maximum range is constant by the relation:

$$R_{\max} v_{\max} = \frac{c\lambda}{8} \quad (32)$$

So the Doppler problem is selecting PRF for a large unambiguous range will cause velocity ambiguity and increasing the velocity will cause range ambiguity.

To overcome this problem, alternate the bursts of pulses at low PRF for range detections and high PRF for velocity detections and use slightly different PRFs in alternating sequences.

The main point in Pulse repetition frequency selection is preventing the Doppler and range ambiguities and maximizing the average transmitted power by the system.

There are tree types of PRF

- High PRF
- Medium PRF
- Low PRF

The Low PRF provides long and accurate unambiguous range results but gives ambiguous Doppler results.
Medium PRF provides ambiguous range and Doppler results but gives information in both range and Doppler. Also it operates with more convenient average transmitted power than low PRF.
High PRF waveforms provide the best average transmitted power and have the capability of rejecting main beam clutters. It also provides high Doppler resolution and Doppler unambiguity. But in contrast to these it is very ambiguous in range detection.

Although the principles of operation are similar, the MTI radars are generally not categorized as pulse Doppler radar type.
Radars operate with both constant and varying PRFs. Especially for moving targets the Moving Target Indicator (MTI) radars use varying PRF to avoid blind speeds, range and Doppler ambiguities where this type of usage is known as PRF staggering or PRF jitter. It is also useful in preventing the locking of jammers to the operating radars.

In addition to these factors, there also some other factors effecting on radar performance as:

•Signal Reception
•Radar Cross Section of Target
•Signal-to-noise ratio
•Pulse Compression
•Receiver Bandwidth
•Receiver Sensitivity
•Pulse Shape
•Power Relation
•Carrier Frequency
•Scan Rate
–Mechanical
–Electronic
•Beam Width
•Antenna aperture
•Pulse Repetition Frequency

Here are some Pulse Doppler Applications and Requirements:[2]

Table 3 Pulse Doppler Applications and Requirements

RADAR APPLICATION	REQUIREMENTS
Airborne or space borne surveillance	Long detection range; accurate range data
Airborne interceptor or fire control	Medium detection range; accurate range, velocity data
Ground-based surveillance	Medium detection range; accurate range data
Battlefield surveillance (slow-moving target detection)	Medium detection range; accurate range, velocity data
Missile seeker	May not need true range information
Ground-based weapon control	Short range; accurate range, velocity data
Meteorological	High velocity and range data resolution
Missile warning	Short detection range; very low false- alarm rate

B. :THE FLOWCHARTS OF FUNCTIONS AND ALGORITHMS

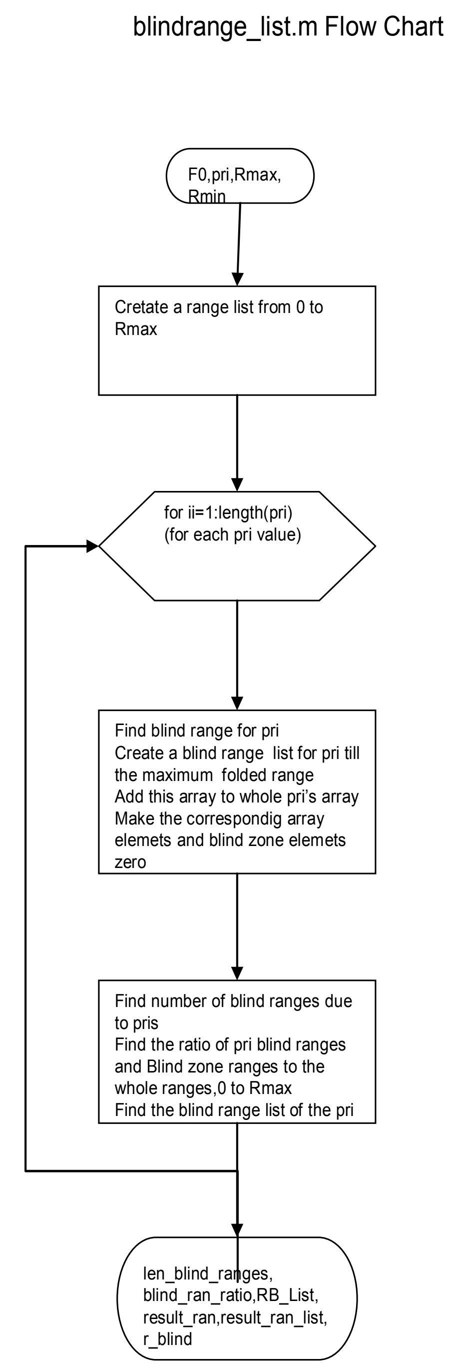

Figure B. 1 blindrange_list.m Flow Chart

blindvelocity_list.m Flow Chart

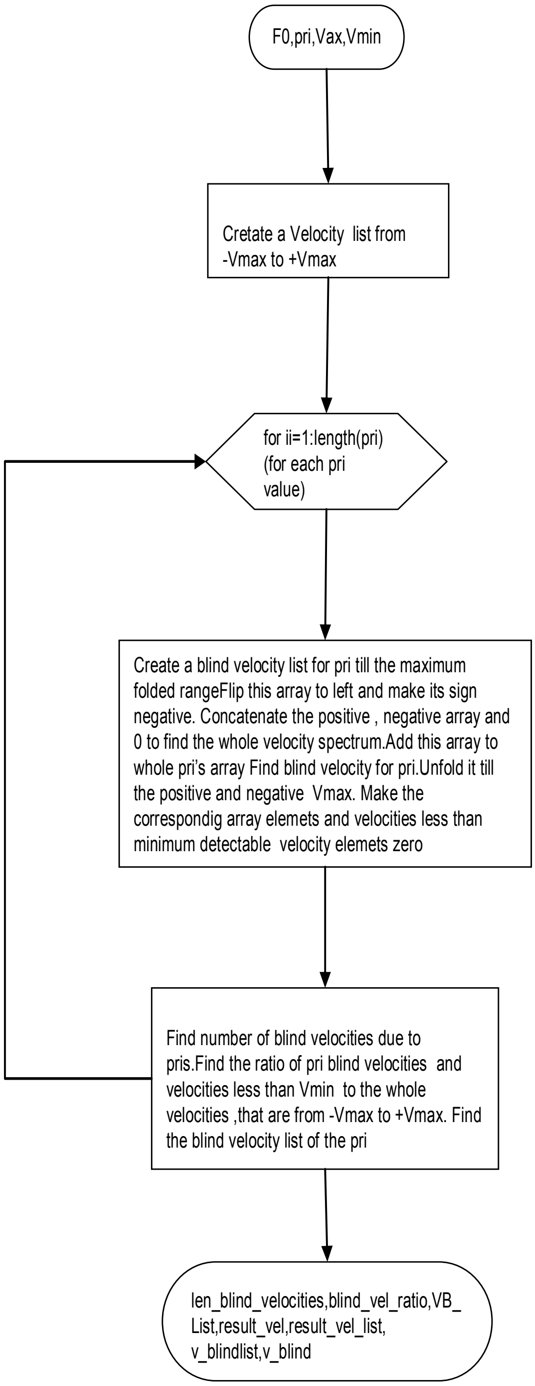

Figure B. 2 blindrange_list.m Flow Chart

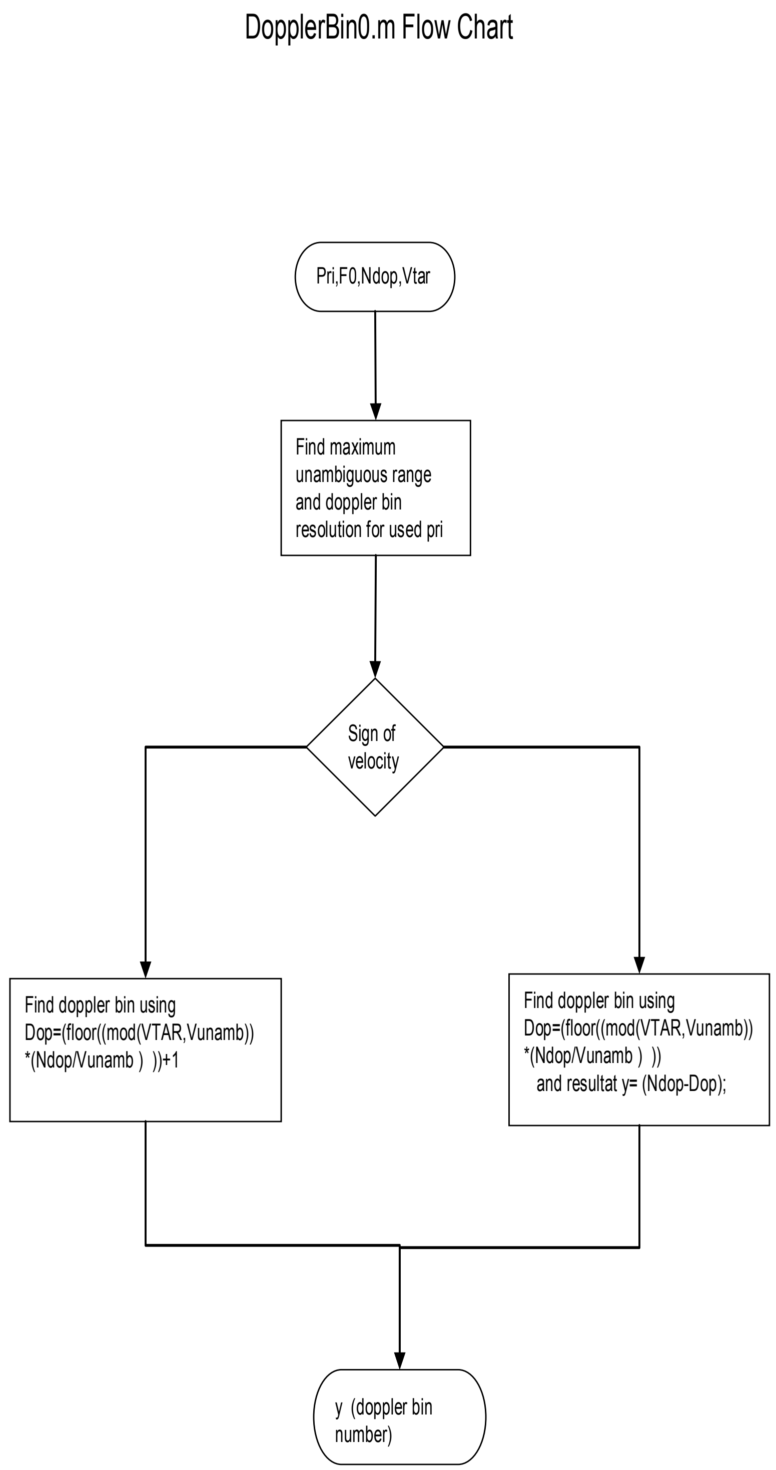

Figure B. 3 DopplerBin0.m Flow Chart

Find_Pd_Range.m Flow Chart

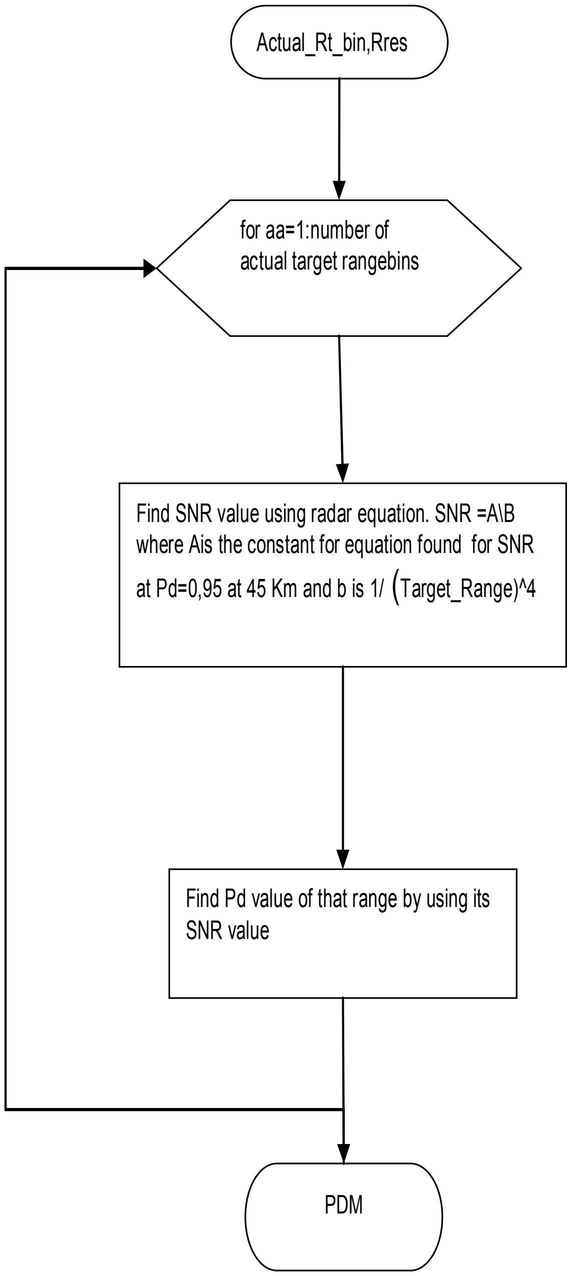

Figure B. 4 Find_Pd_Range.m Flow Chart

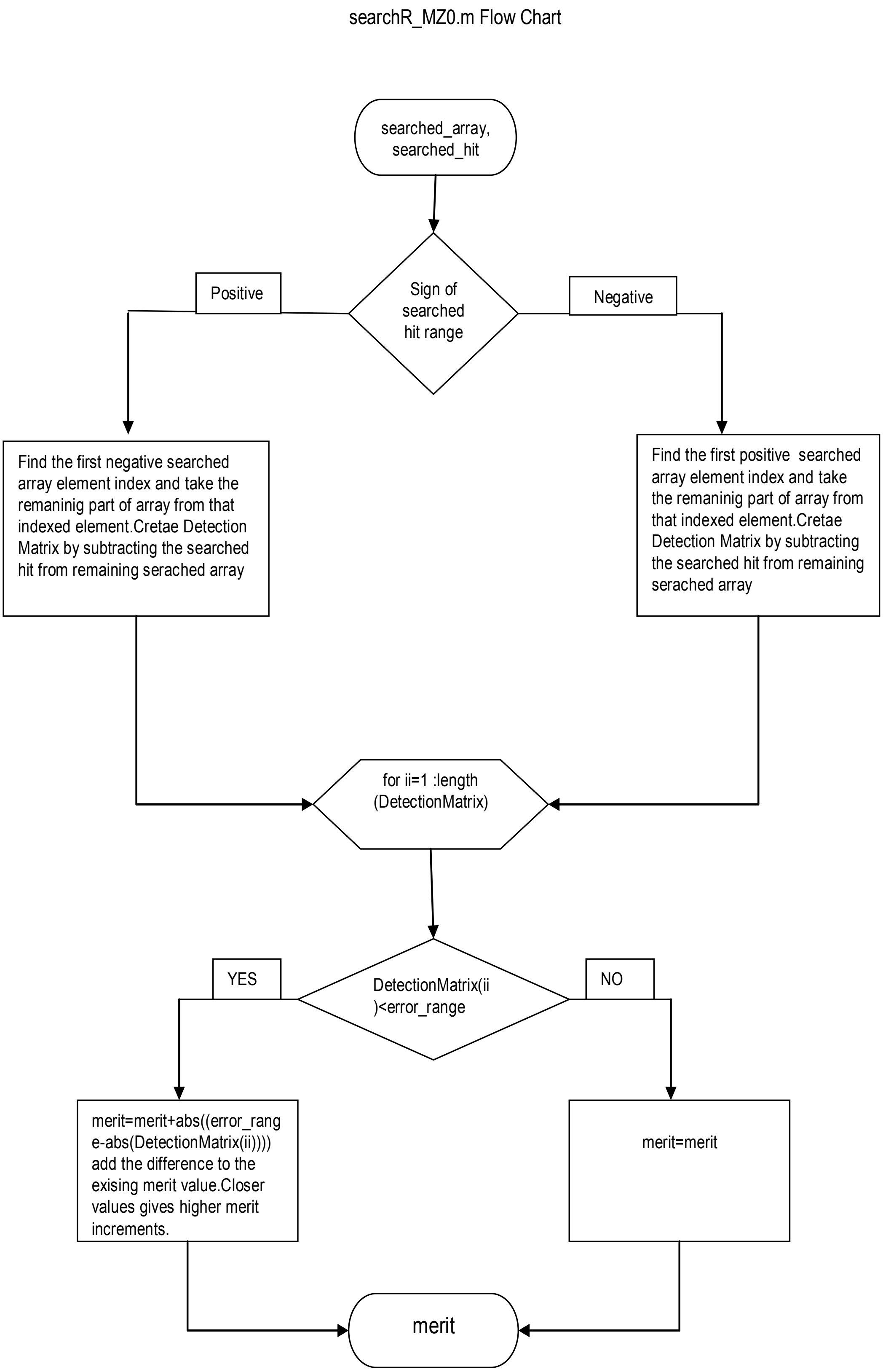

Figure B. 5 searchR_MZ0.m Flow Chart

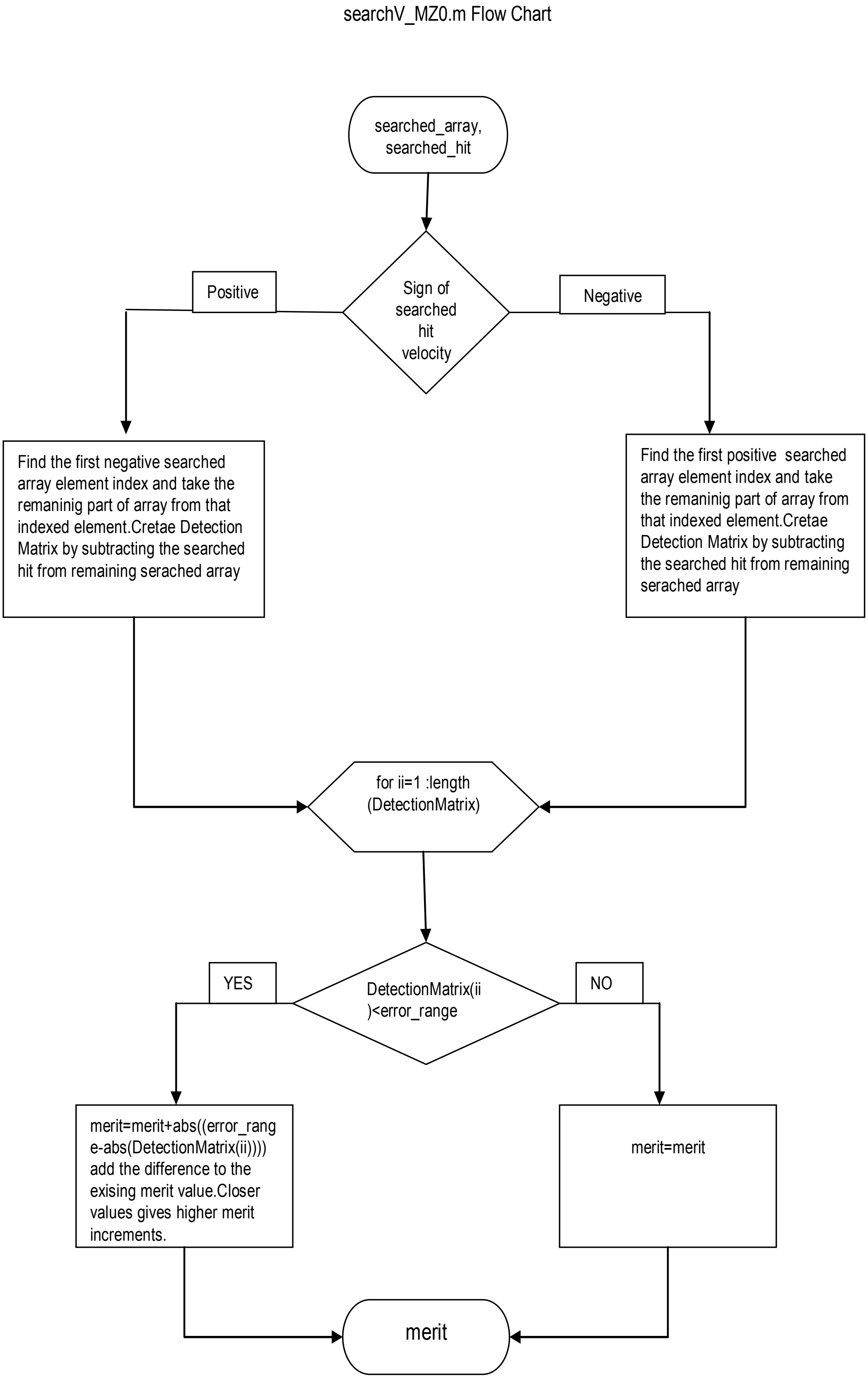

Figure B. 6 searchV_MZ0.m Flow Chart

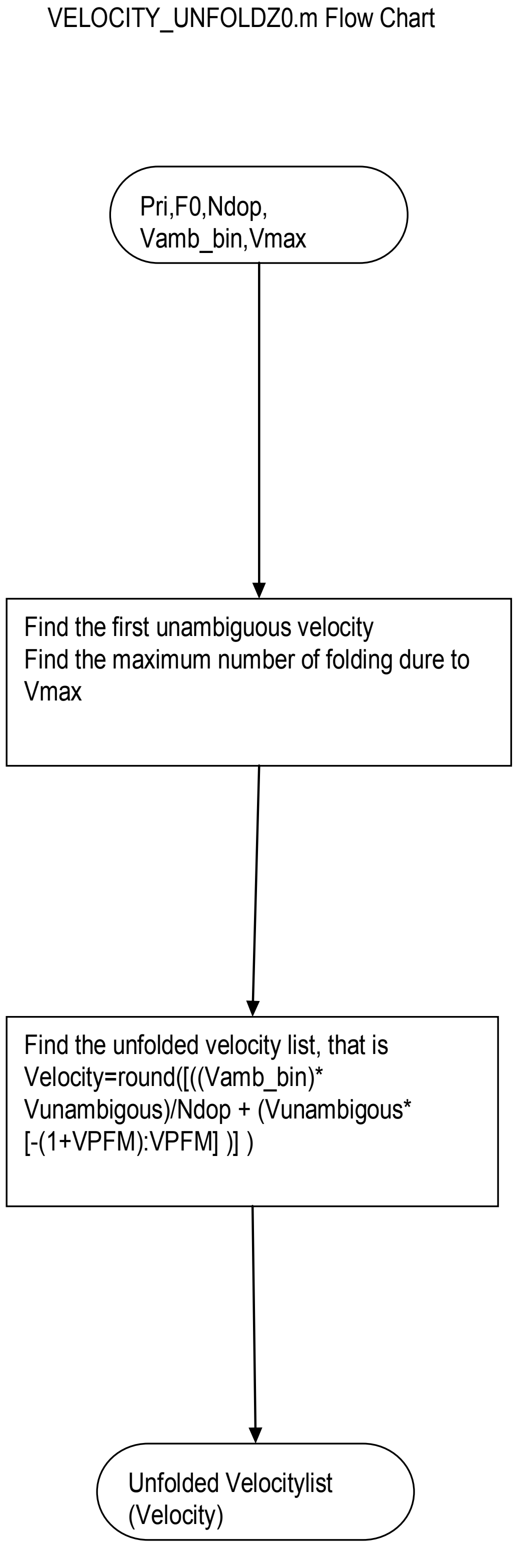

Figure B. 7 VELOCITY_UNFOLD.m Flow Chart

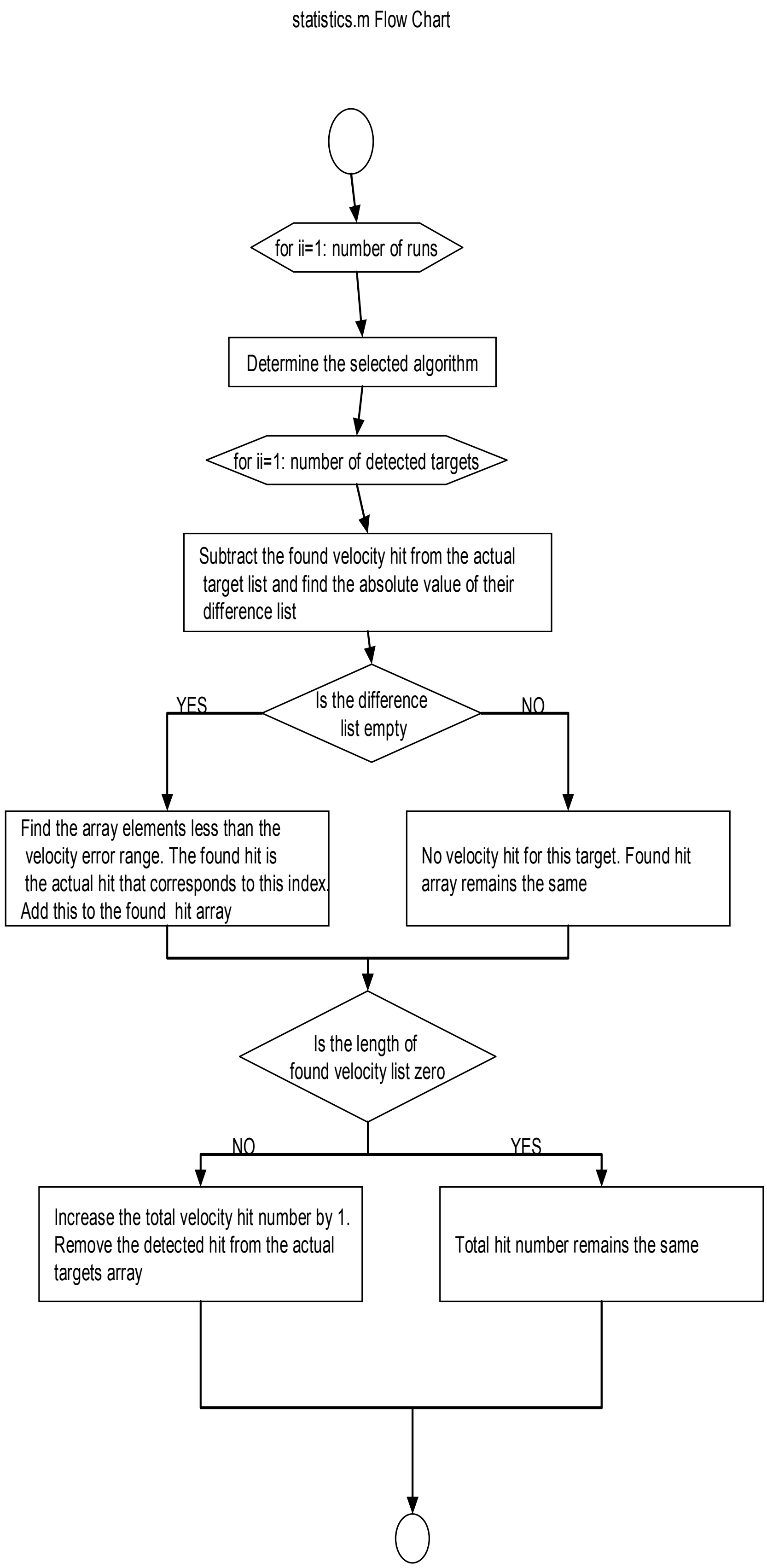

Figure B. 8 statistics.m Flow Chart 1

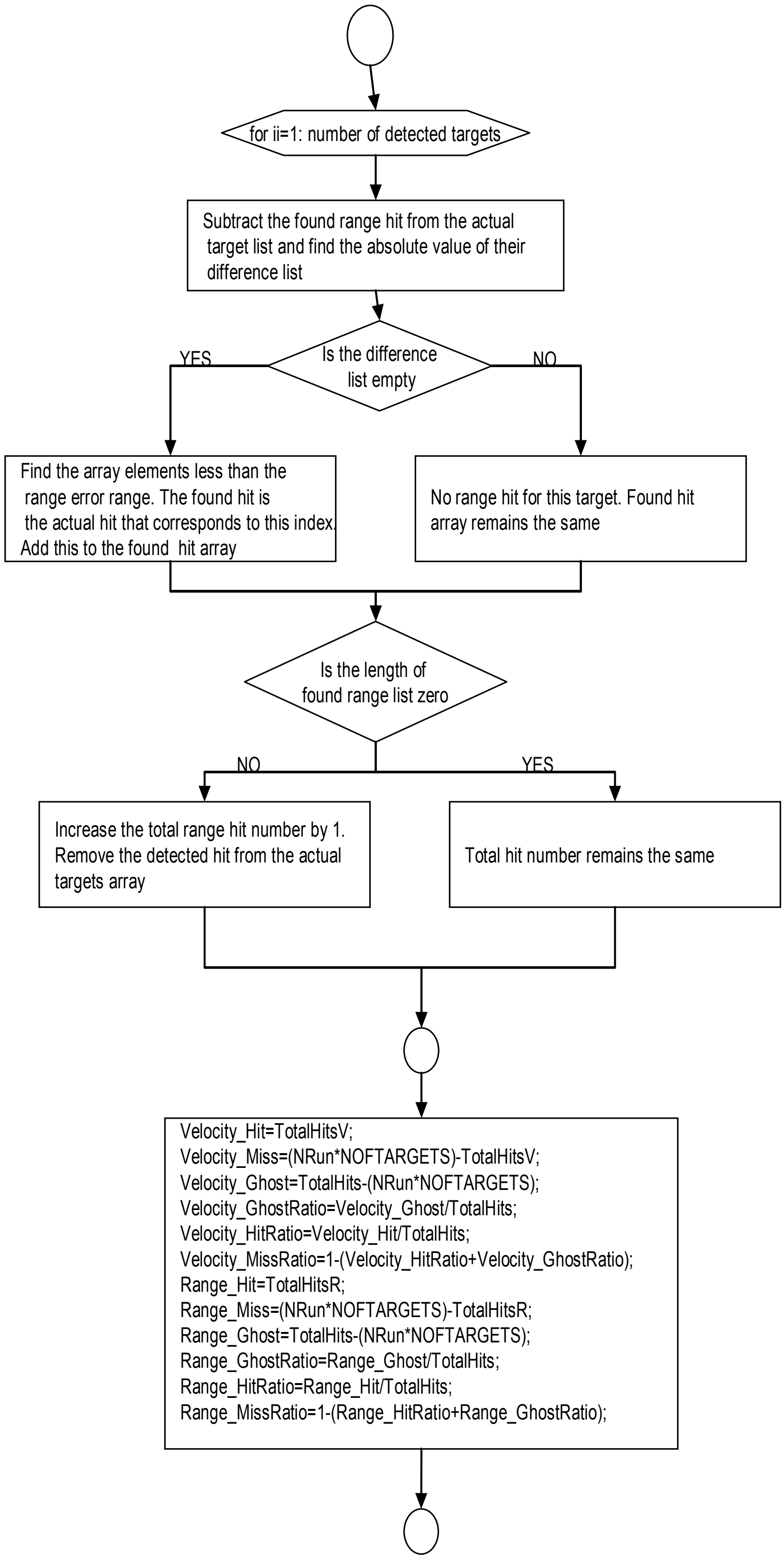

Figure B. 9 statistics.m Flow Chart 2

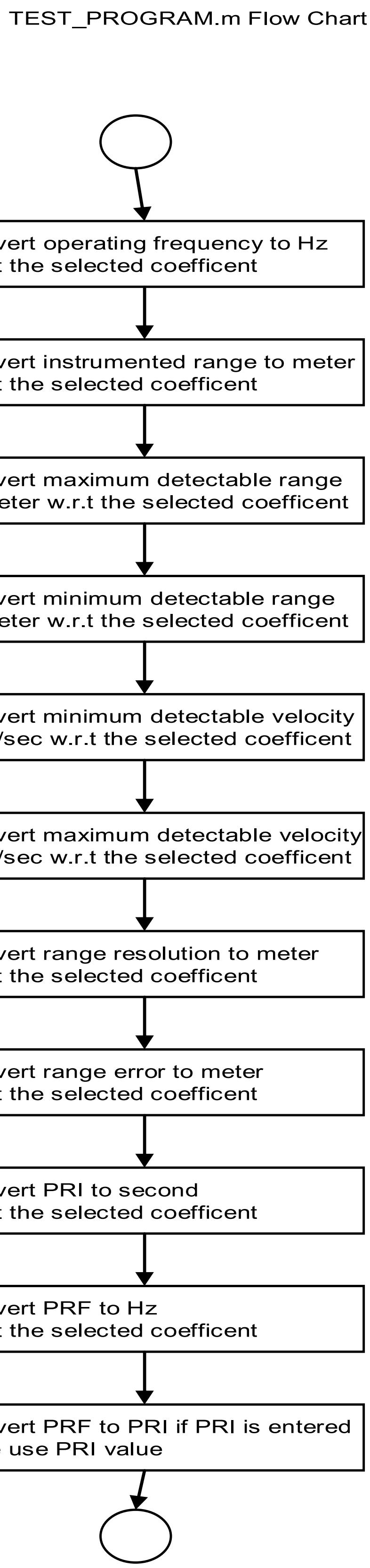

Figure B. 10 TEST_PROGRAM.m Flow Chart 1

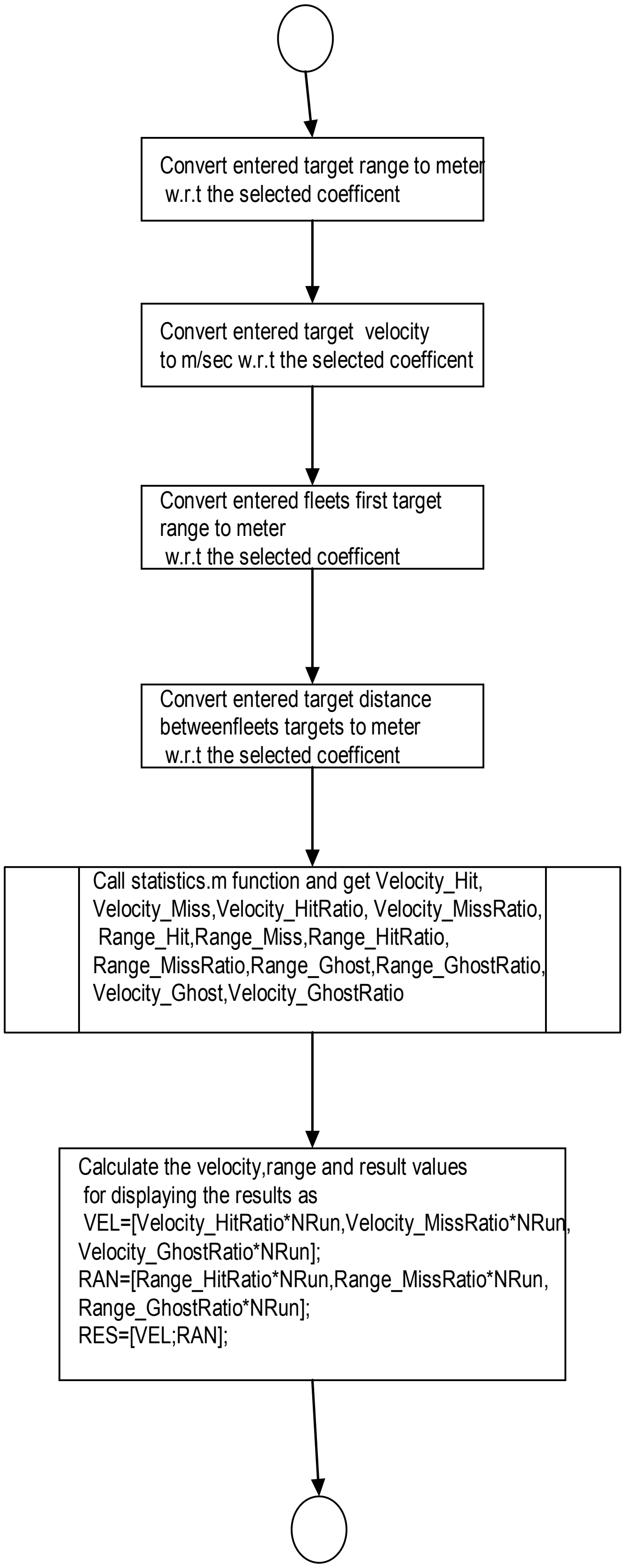

Figure B. 11 TEST_PROGRAM.m Flow Chart 2

PRI_HIT_MIXING_ORDERING.m Flow Chart

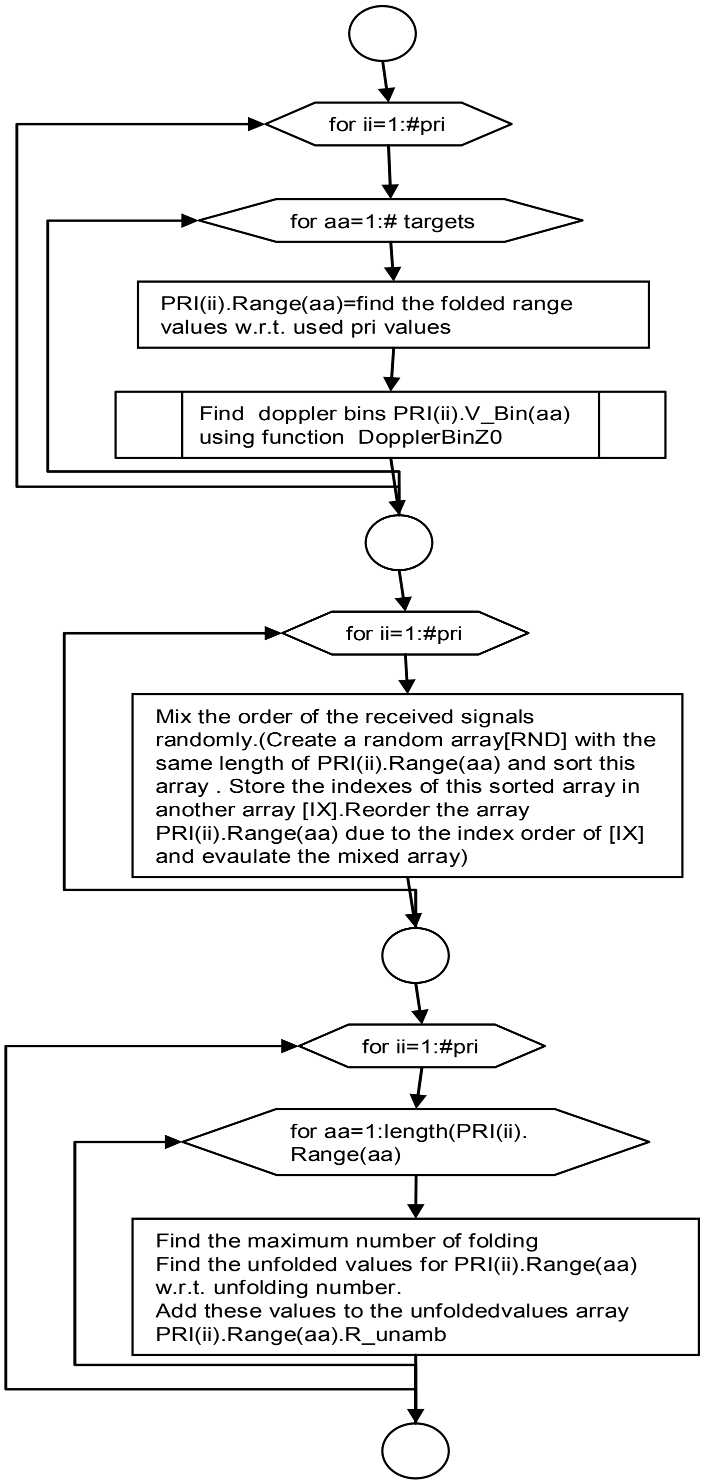

Figure B. 12 PRI_HIT_MIXING_ORDERING.m Flow Chart 1

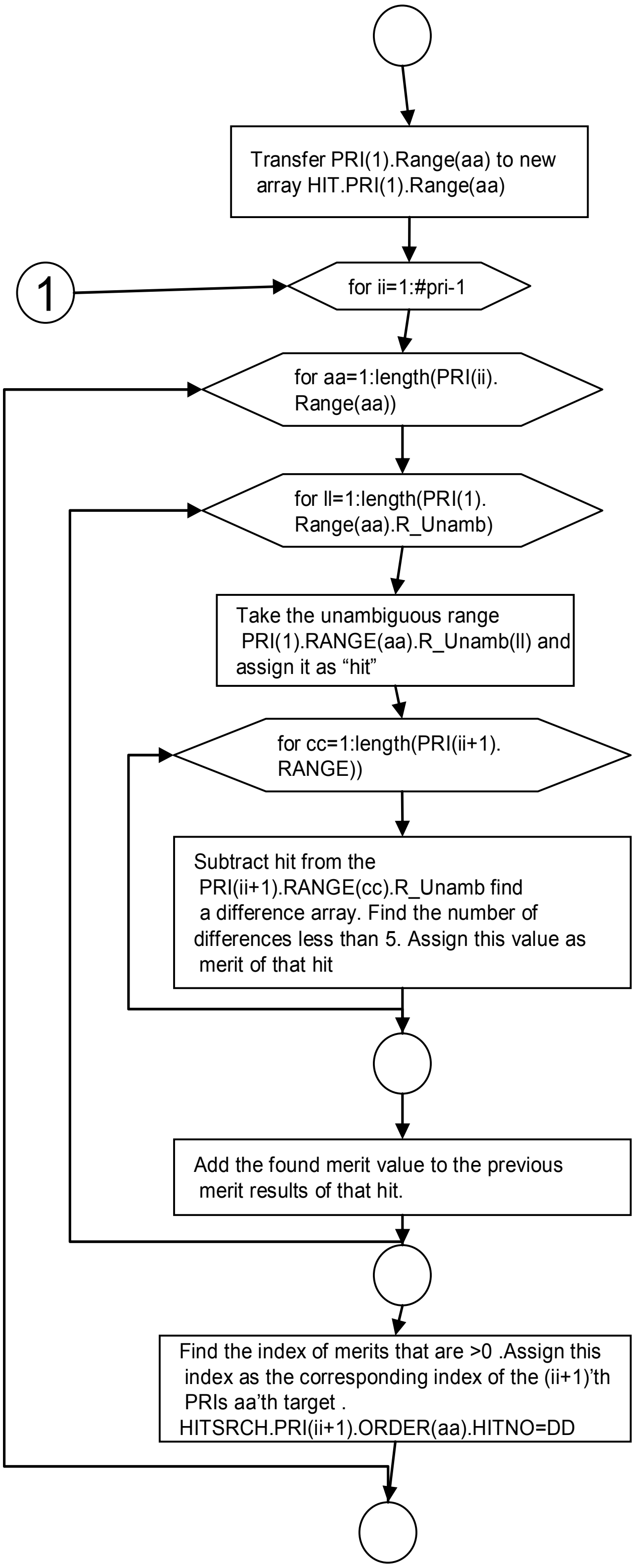

Figure B. 13 PRI_HIT_MIXING_ORDERING.m Flow Chart 2

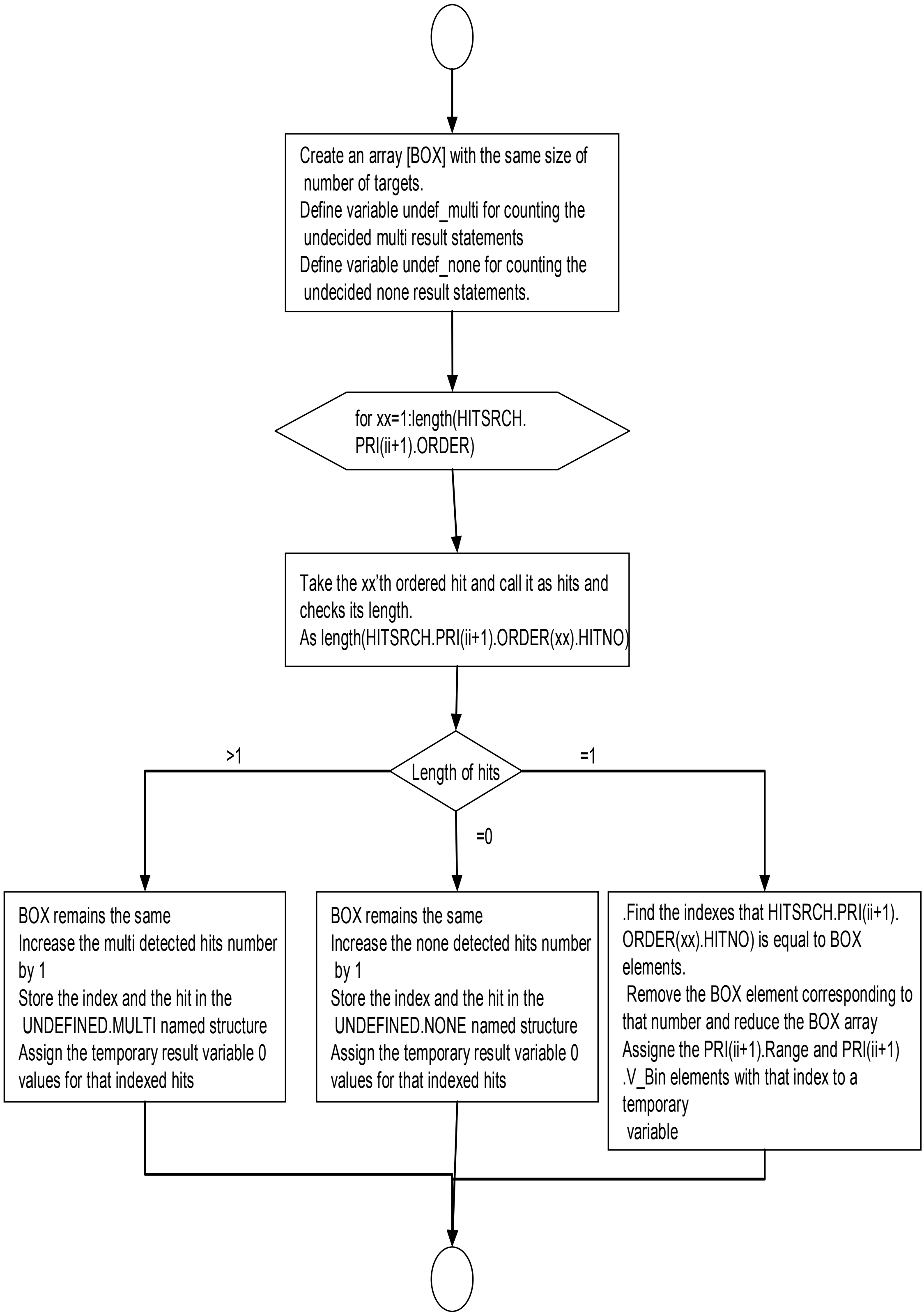

Figure B. 14 PRI_HIT_MIXING_ORDERING.m Flow Chart 3

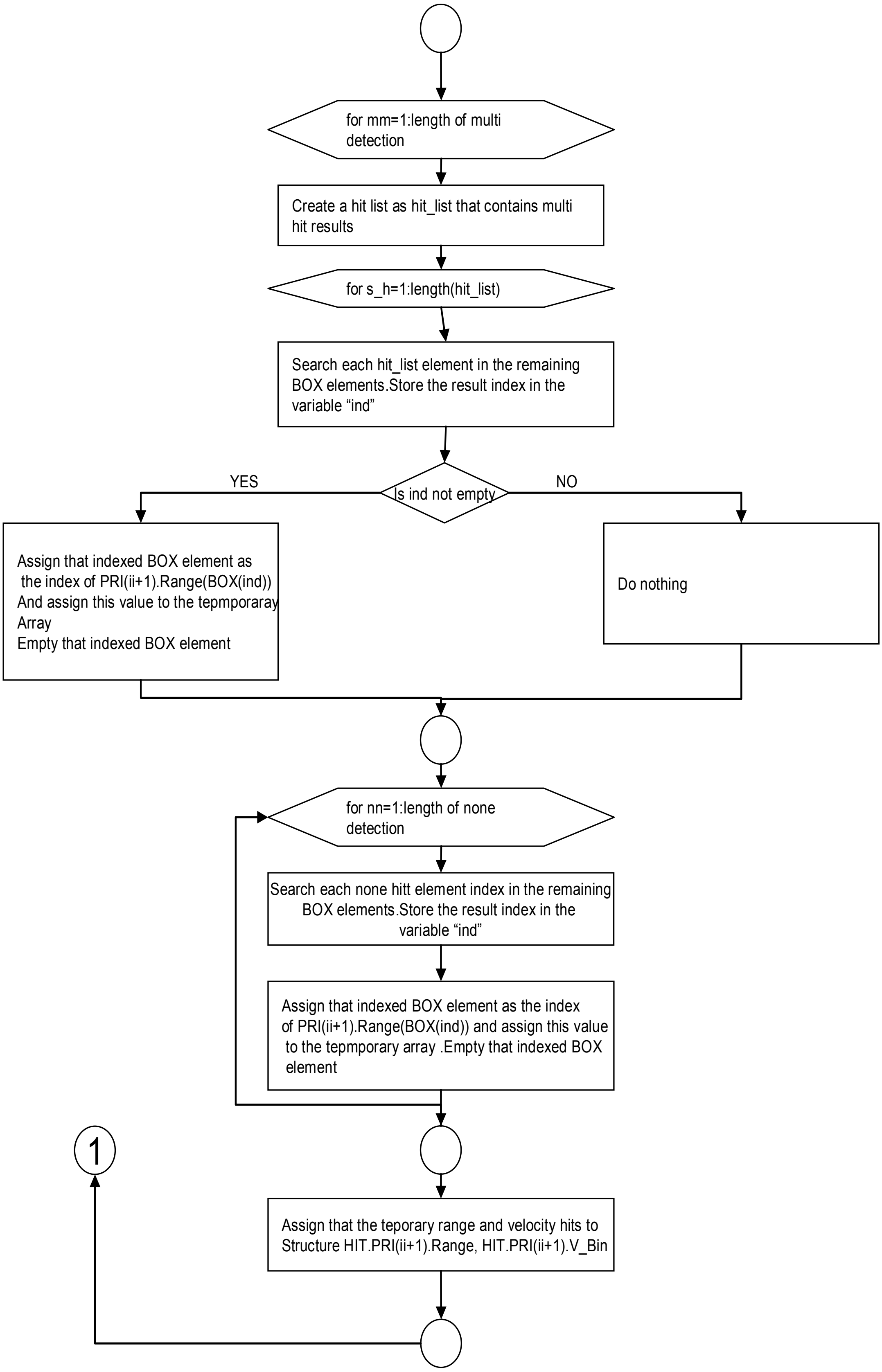

Figure B. 15 PRI_HIT_MIXING_ORDERING.m Flow Chart 4

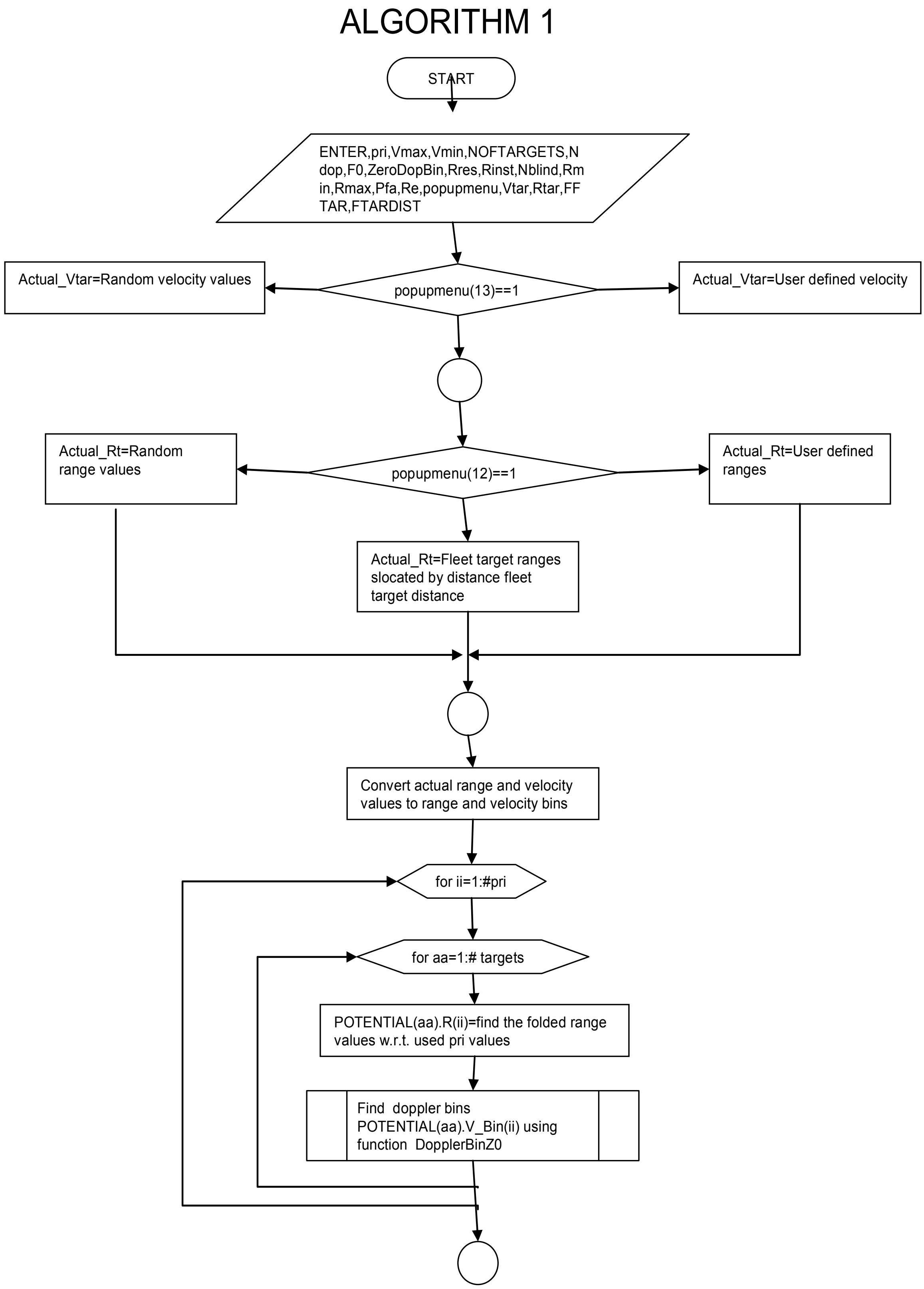

Figure B. 16 ALGORITHM 1 Flow Chart

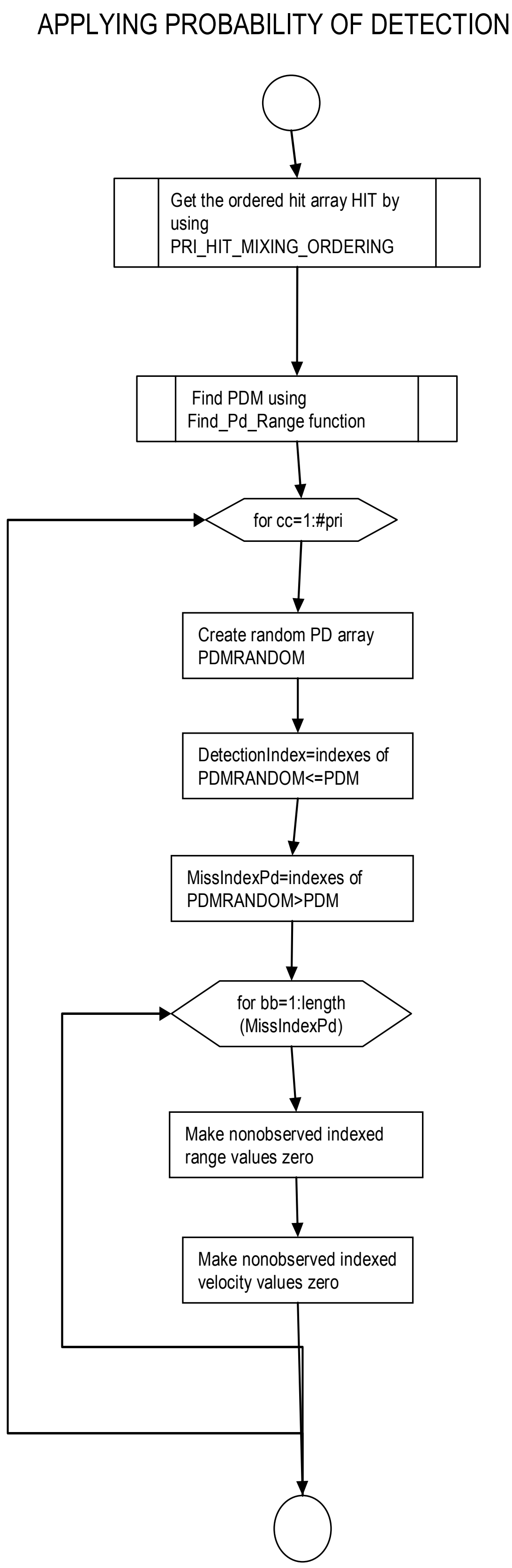

Figure B. 17 Applying Probability of Detection Flow Chart

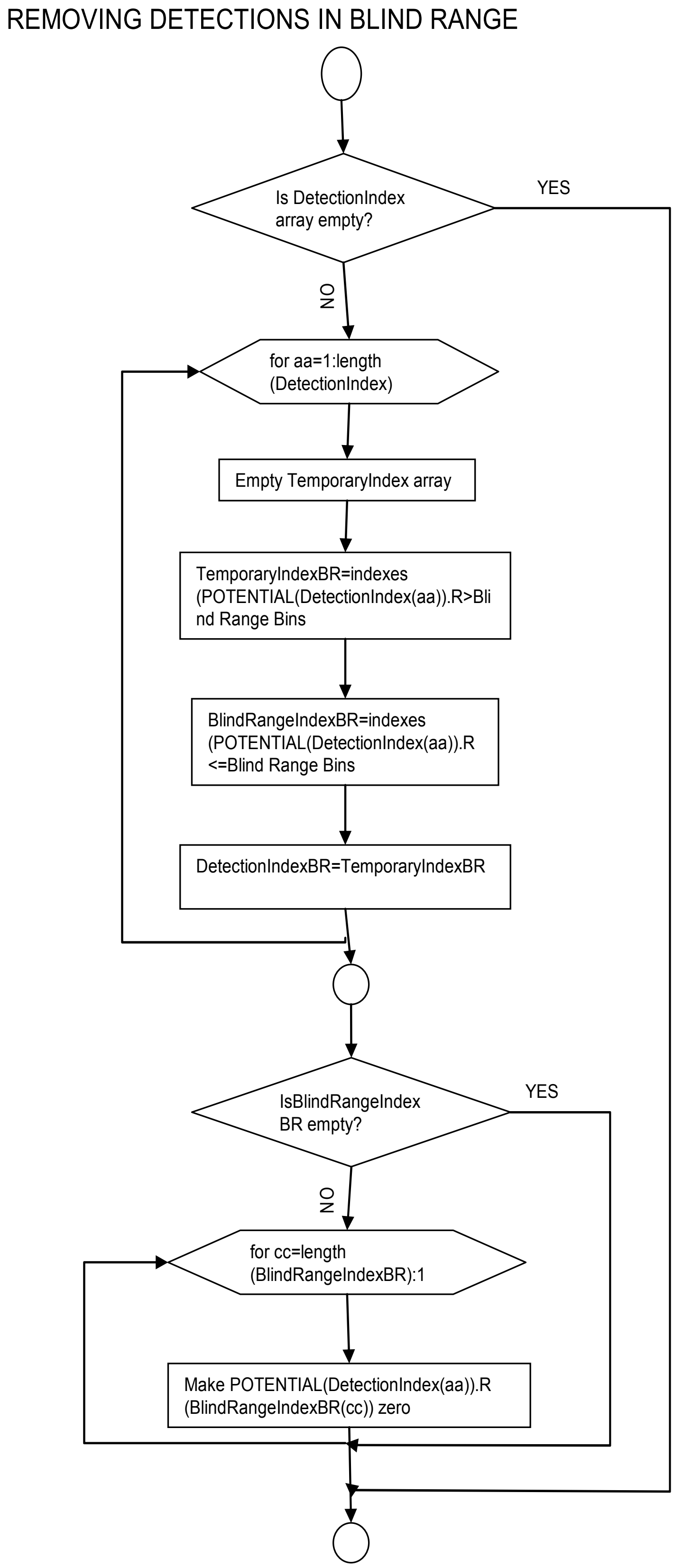

Figure B. 18 Removing Detections in Blind Range Flow Chart

REMOVING DETECTIONS IN BLIND VELOCITY REGION

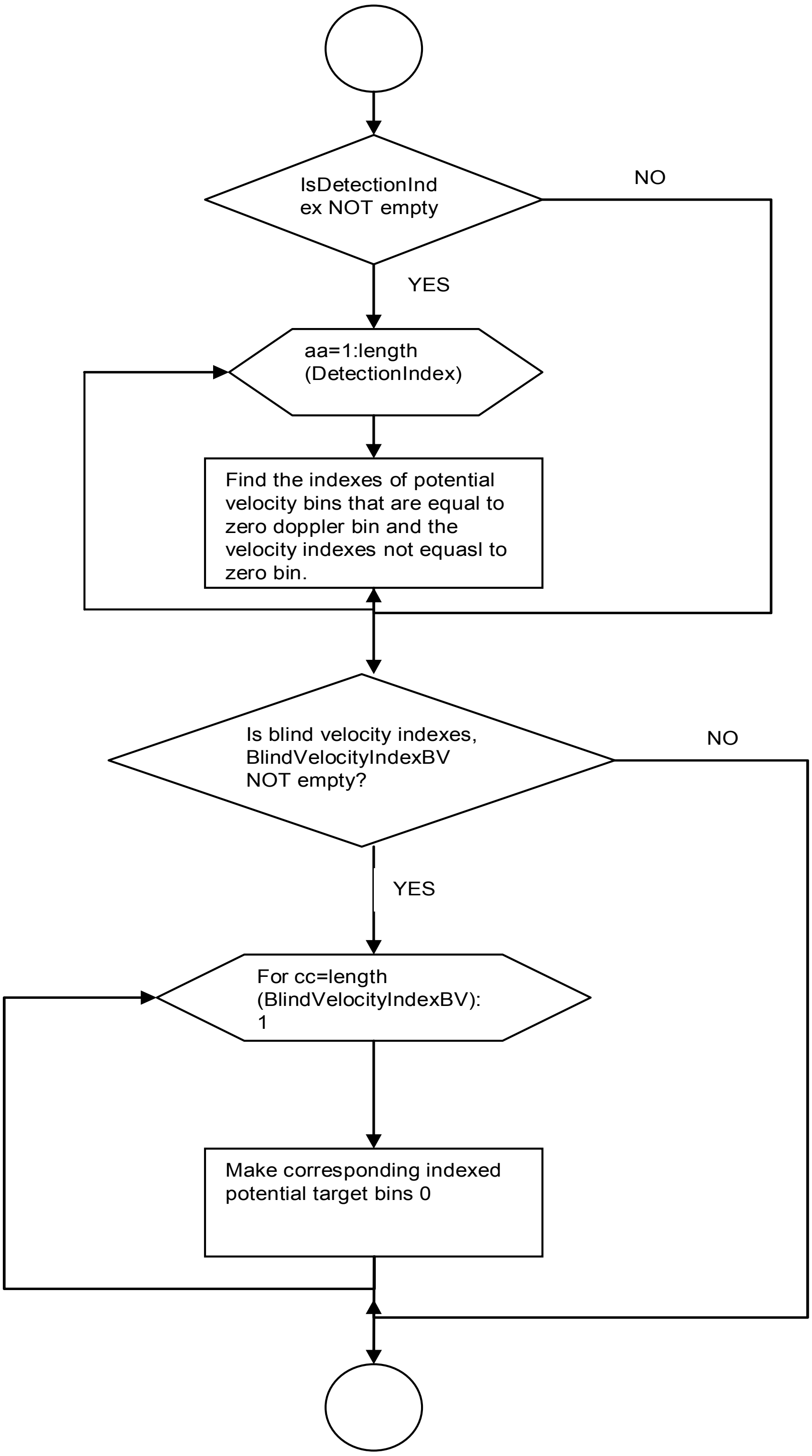

Figure B. 19 Removing Detections in Blind velocity Region Flow Chart

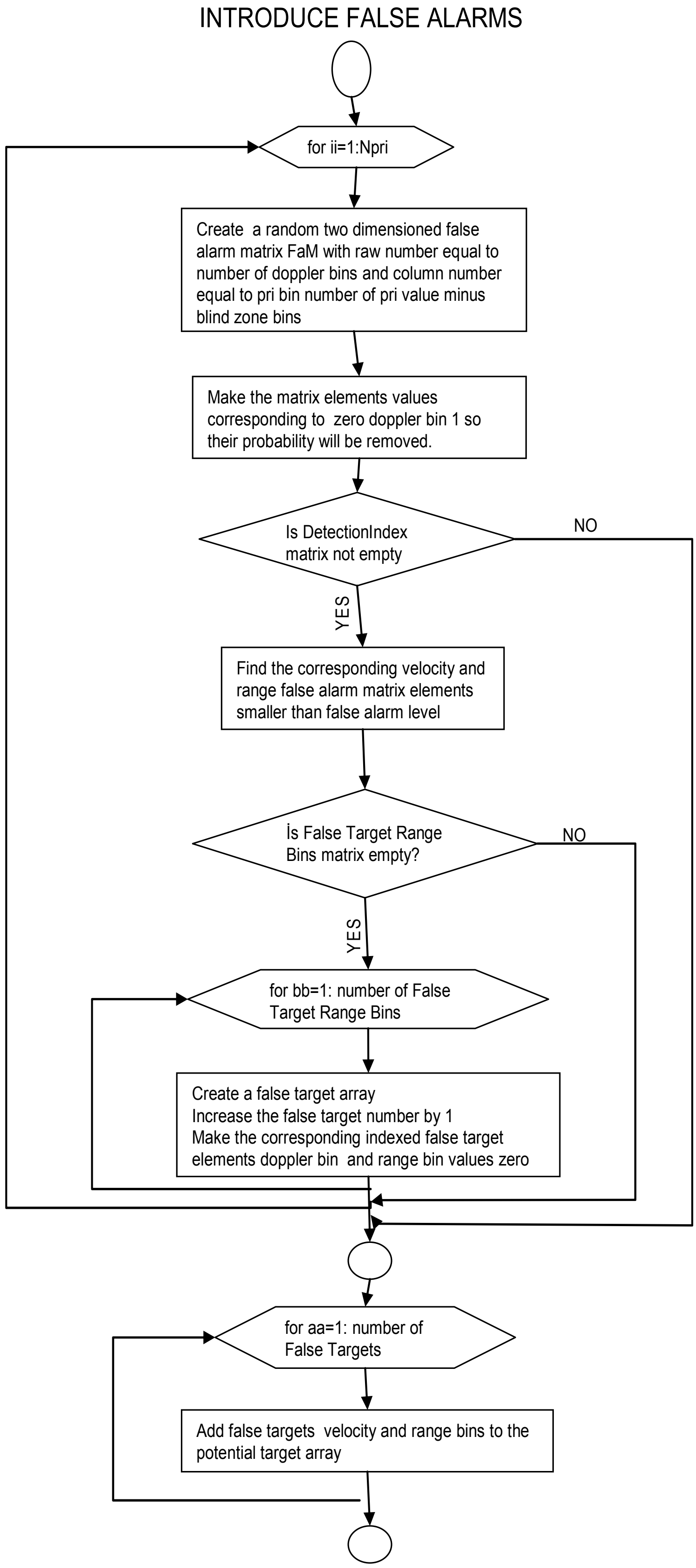

Figure B. 20 Introducing False Alarms Flow Chart

UNFOLDING THE AMBIGUOUS RANGES

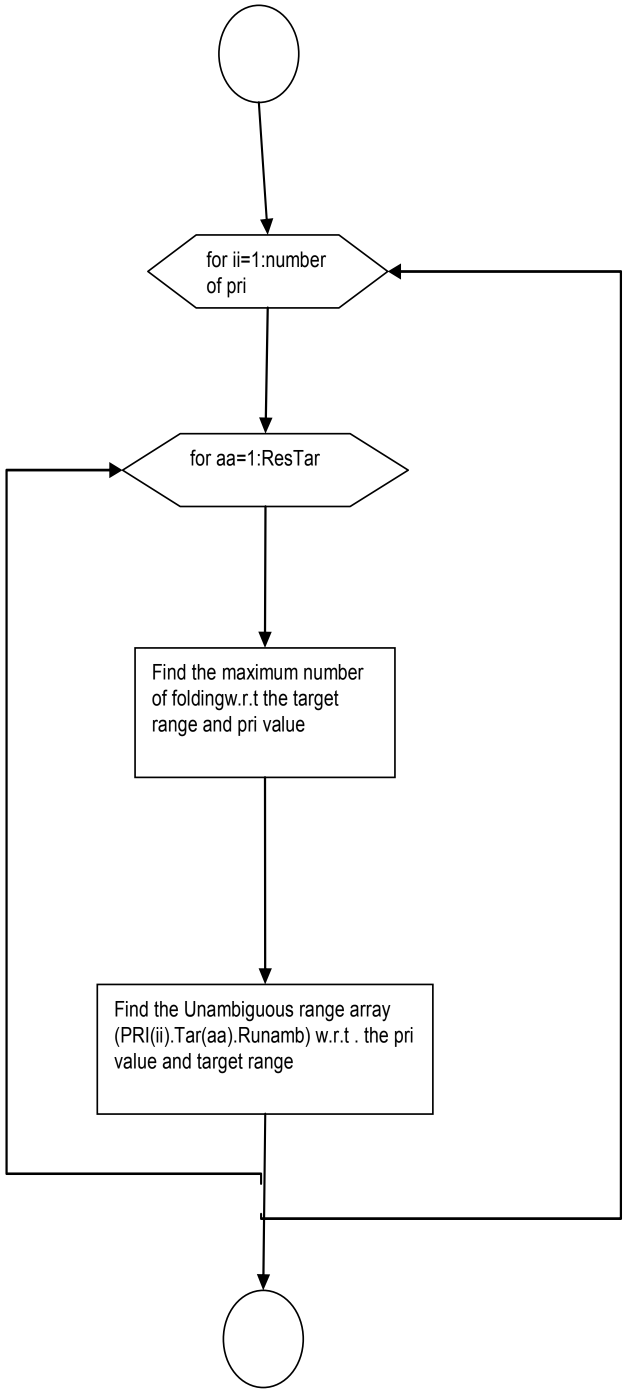

Figure B. 21 Unfolding The Ambiguous Ranges Flow Chart

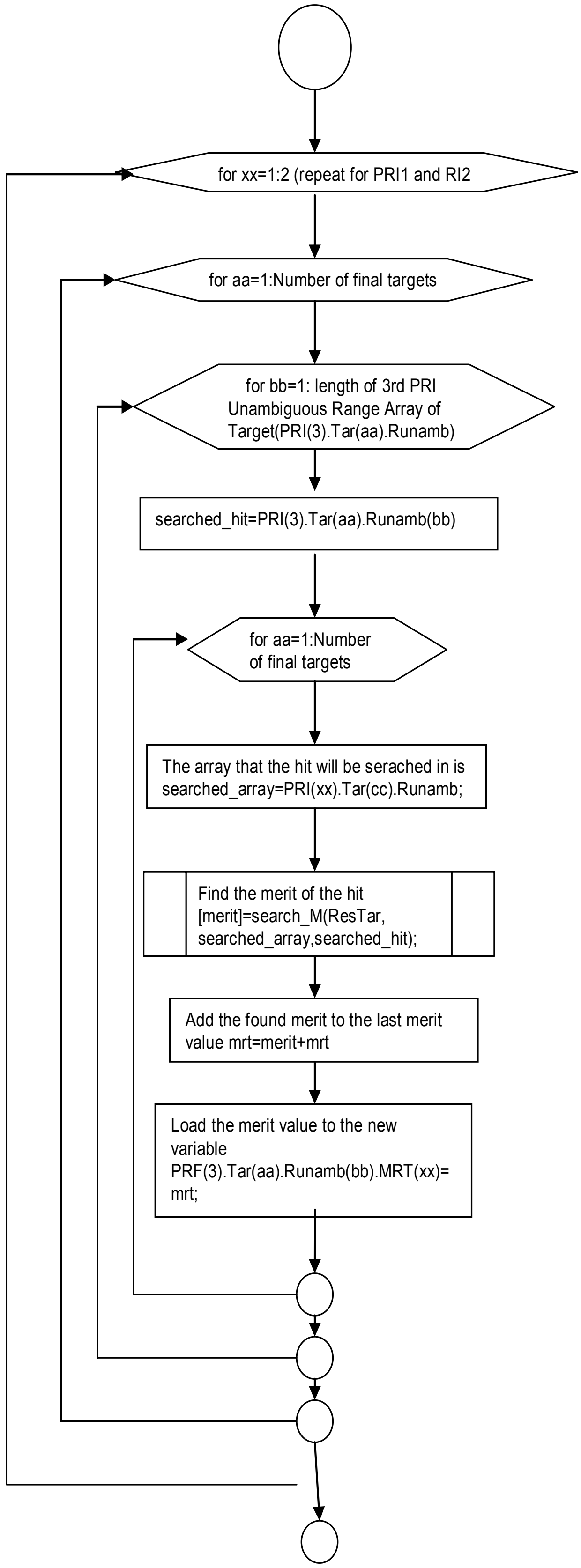

Figure B. 22 Merit Detection Flow Chart

ADD THE MERITS AND DECIDE THE SELECTION OF HIT ;TRUE OR FALSE

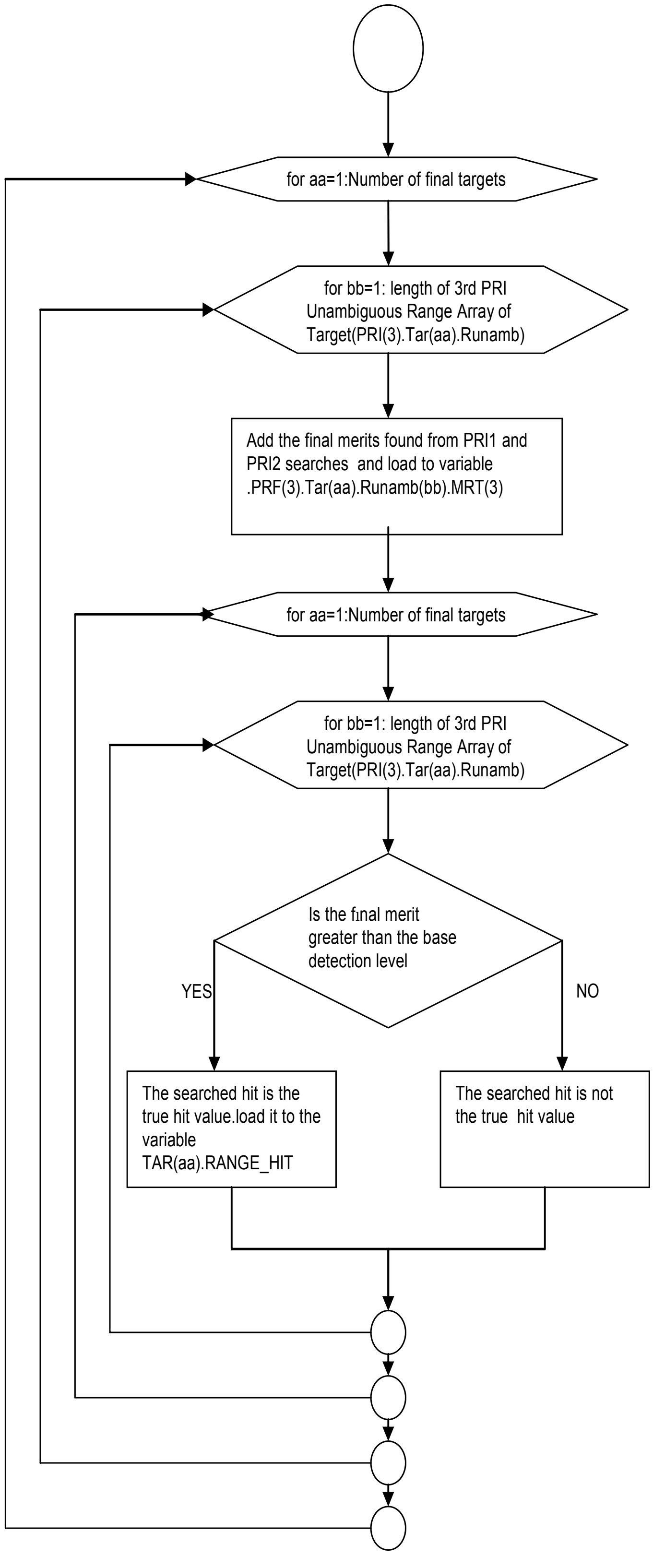

Figure B. 23 Adding Merits and Hit Selection Flow Chart

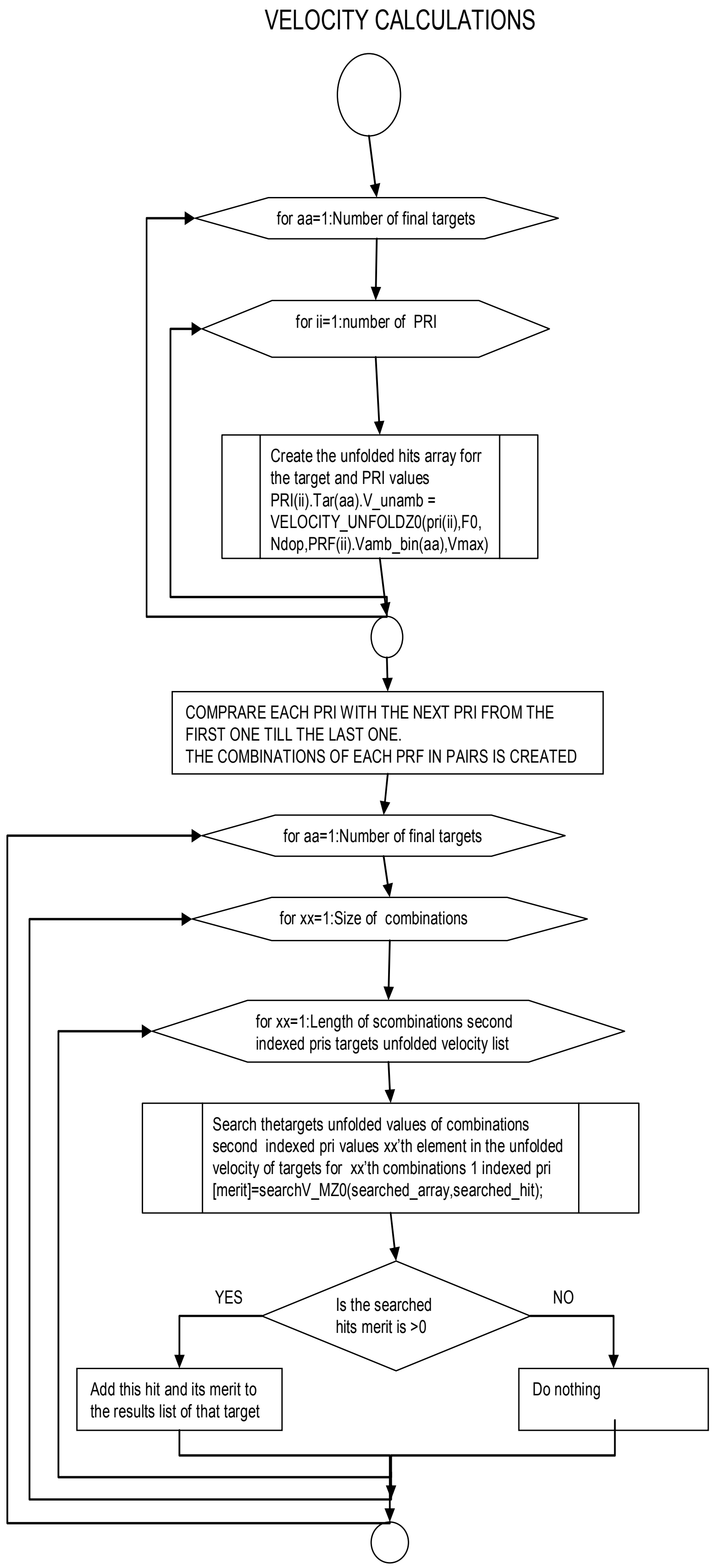

Figure B. 24 Velocity Calculations Flow Chart

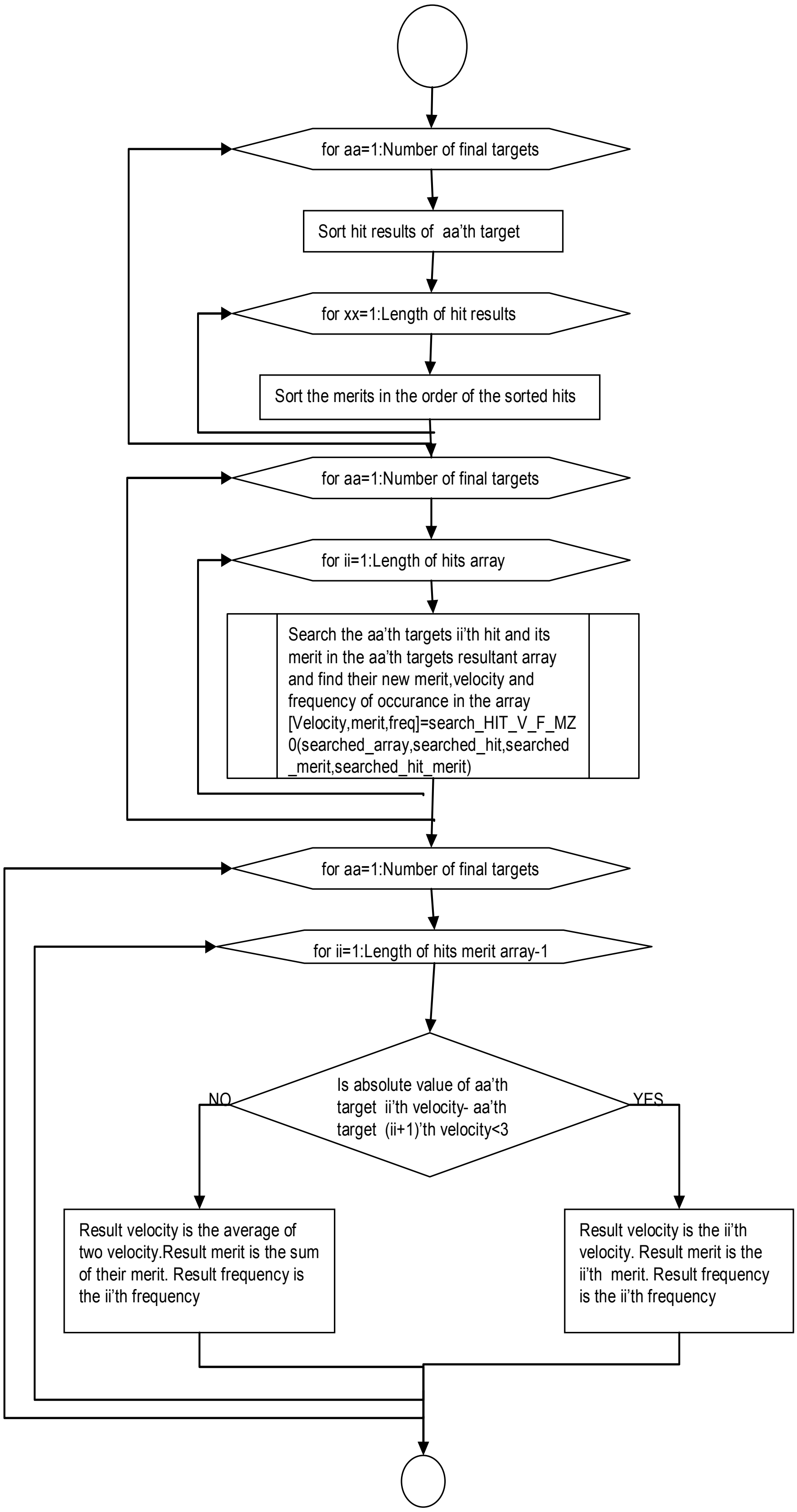

Figure B. 25 Merit Detection Flow Chart

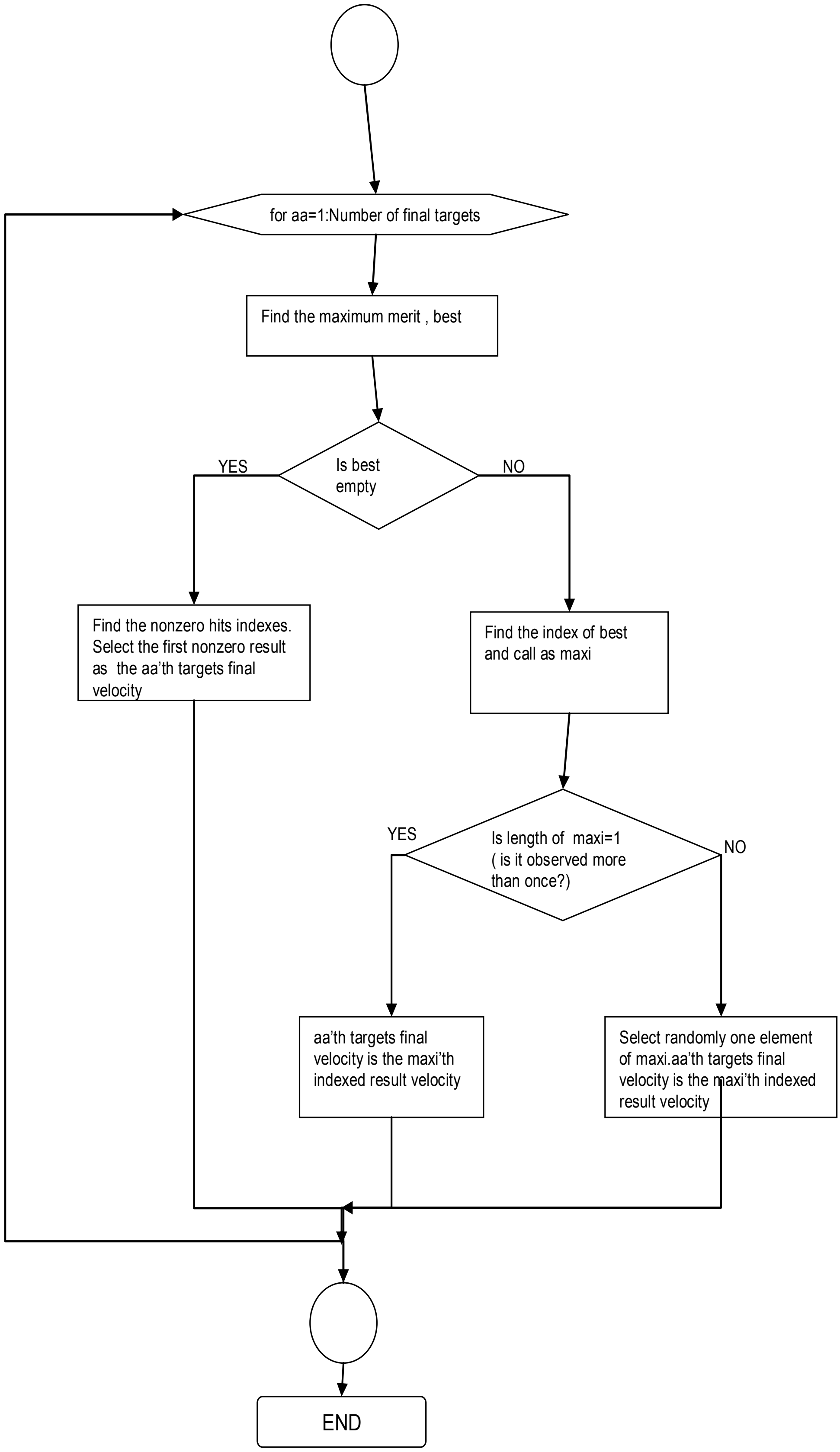

Figure B. 26 Velocity Hit Decision Flow Chart

ALGORITHM 2

Figure B. 27 Algorithm 2 Flow Chart

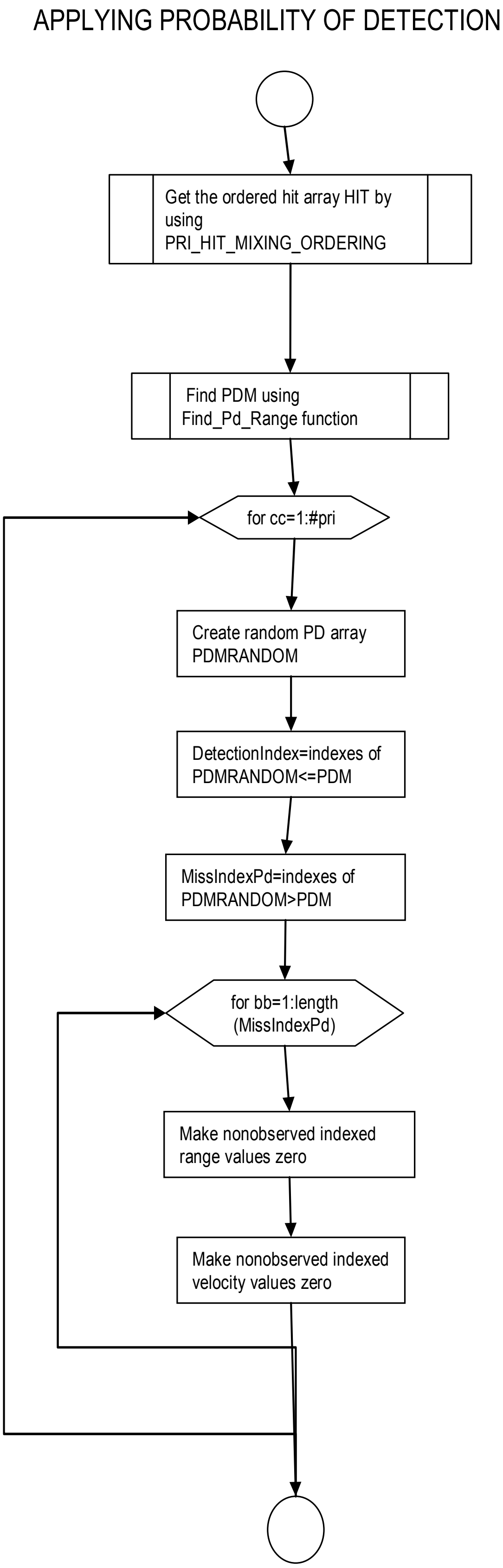

Figure B. 28 Applying Probability of Detection Flow Chart

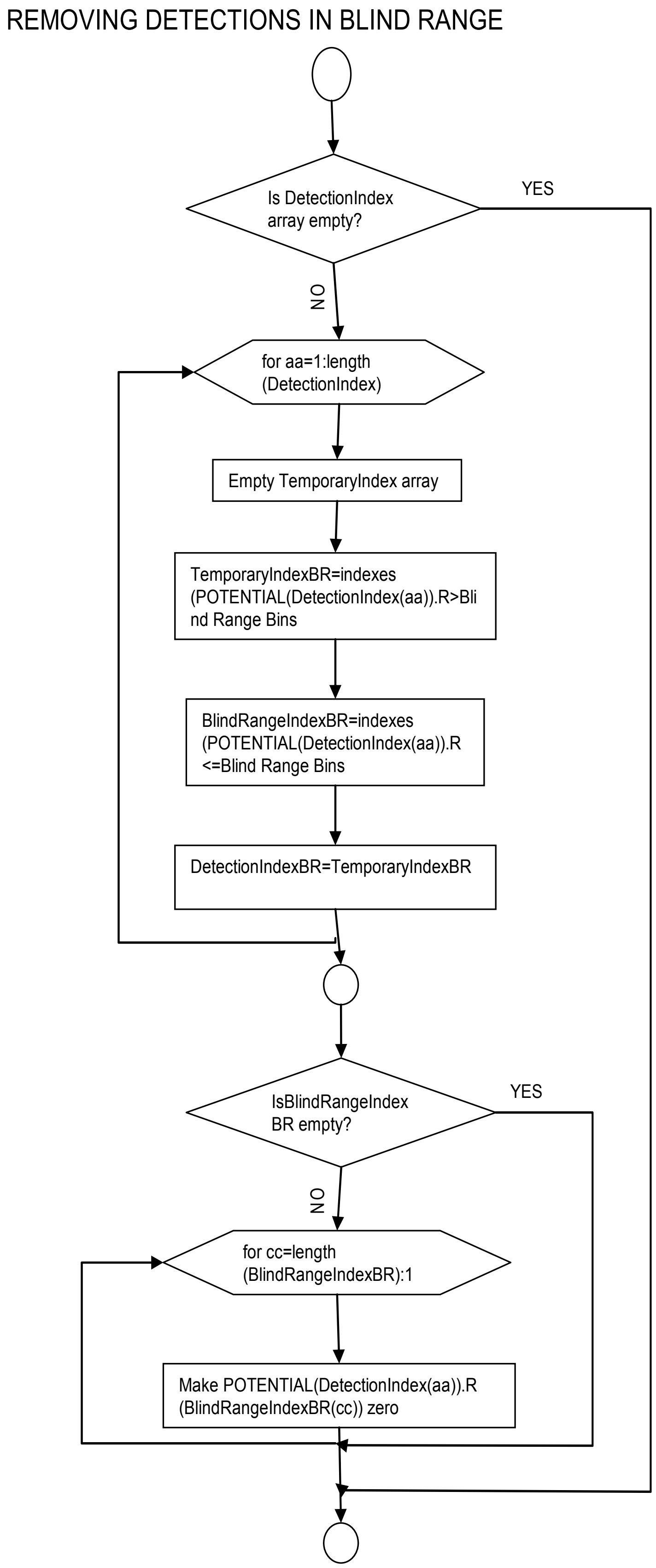

Figure B. 29 Removing Detections in Blind Velocity Flow Chart

REMOVING DETECTIONS IN BLIND VELOCITY REGION

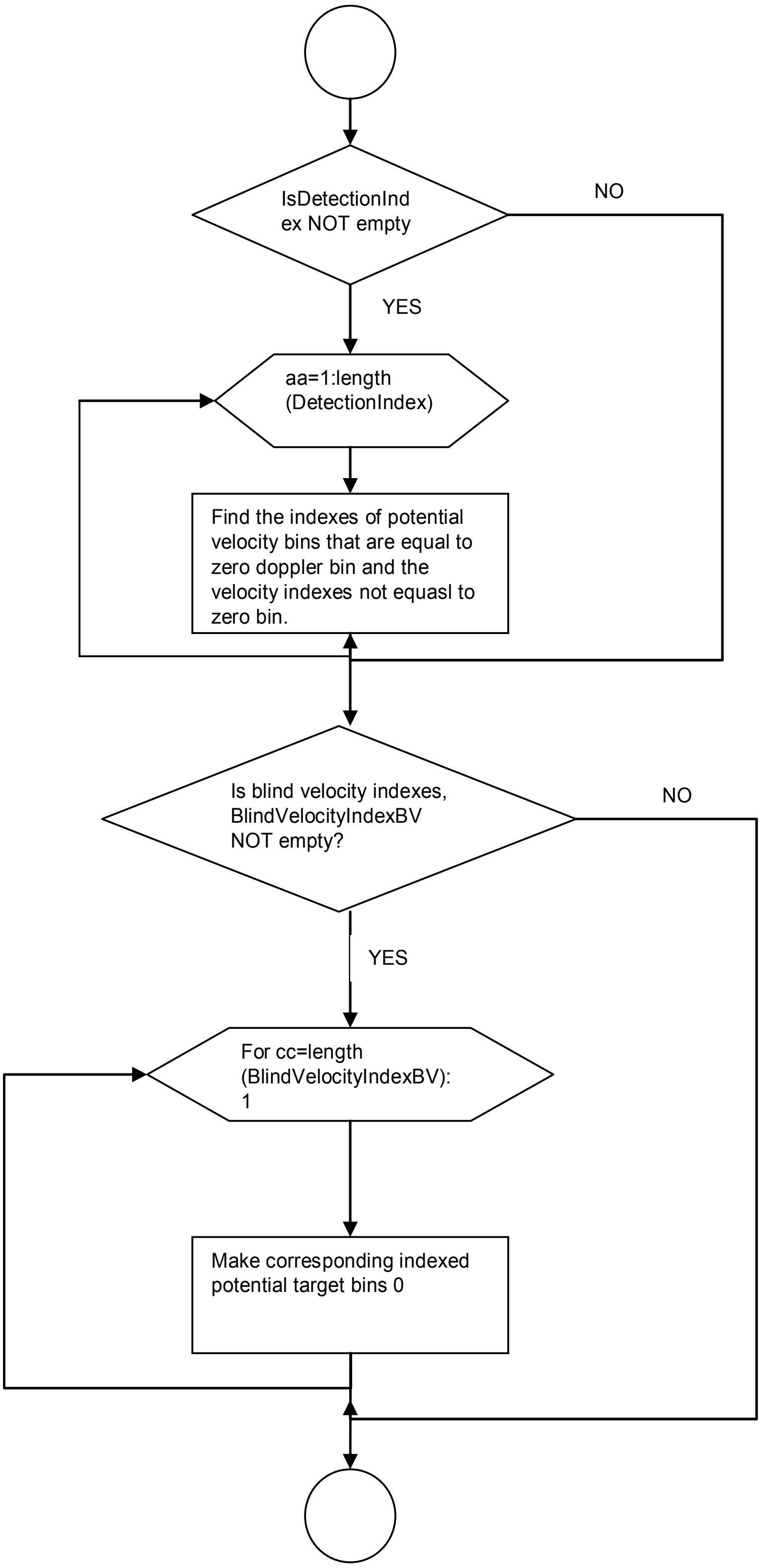

Figure B. 30 Removing Detections in Blind Velocity Region Flow Chart

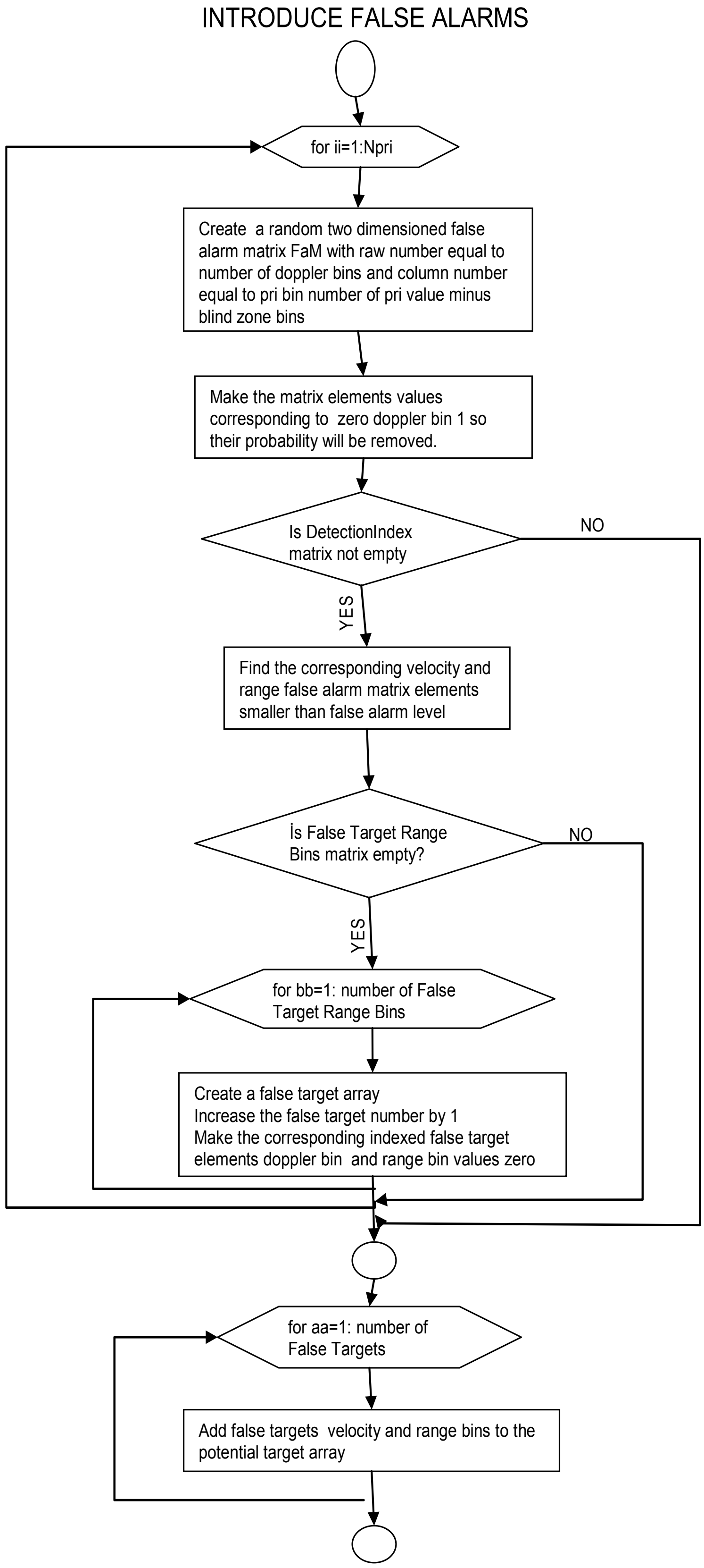

Figure B. 31 Introduce False Alarms Flow Chart

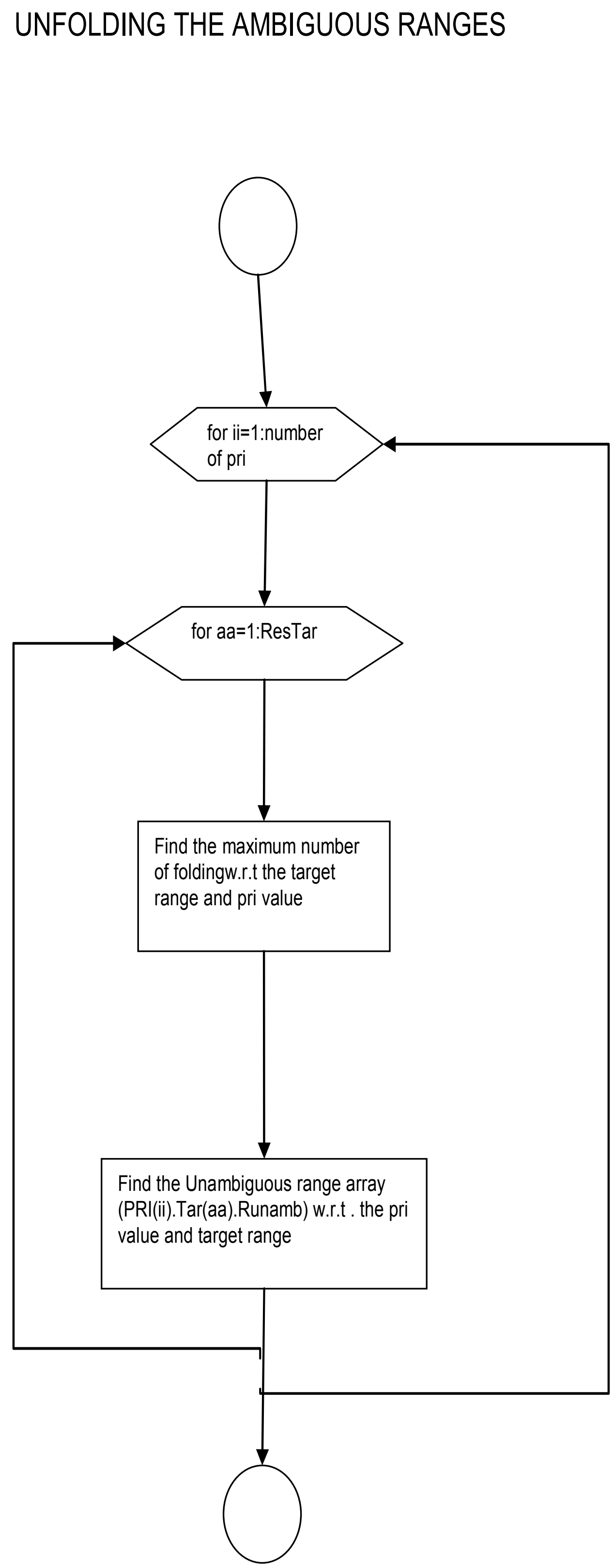

Figure B. 32 Unfolding The Ambiguous Ranges Flow Chart

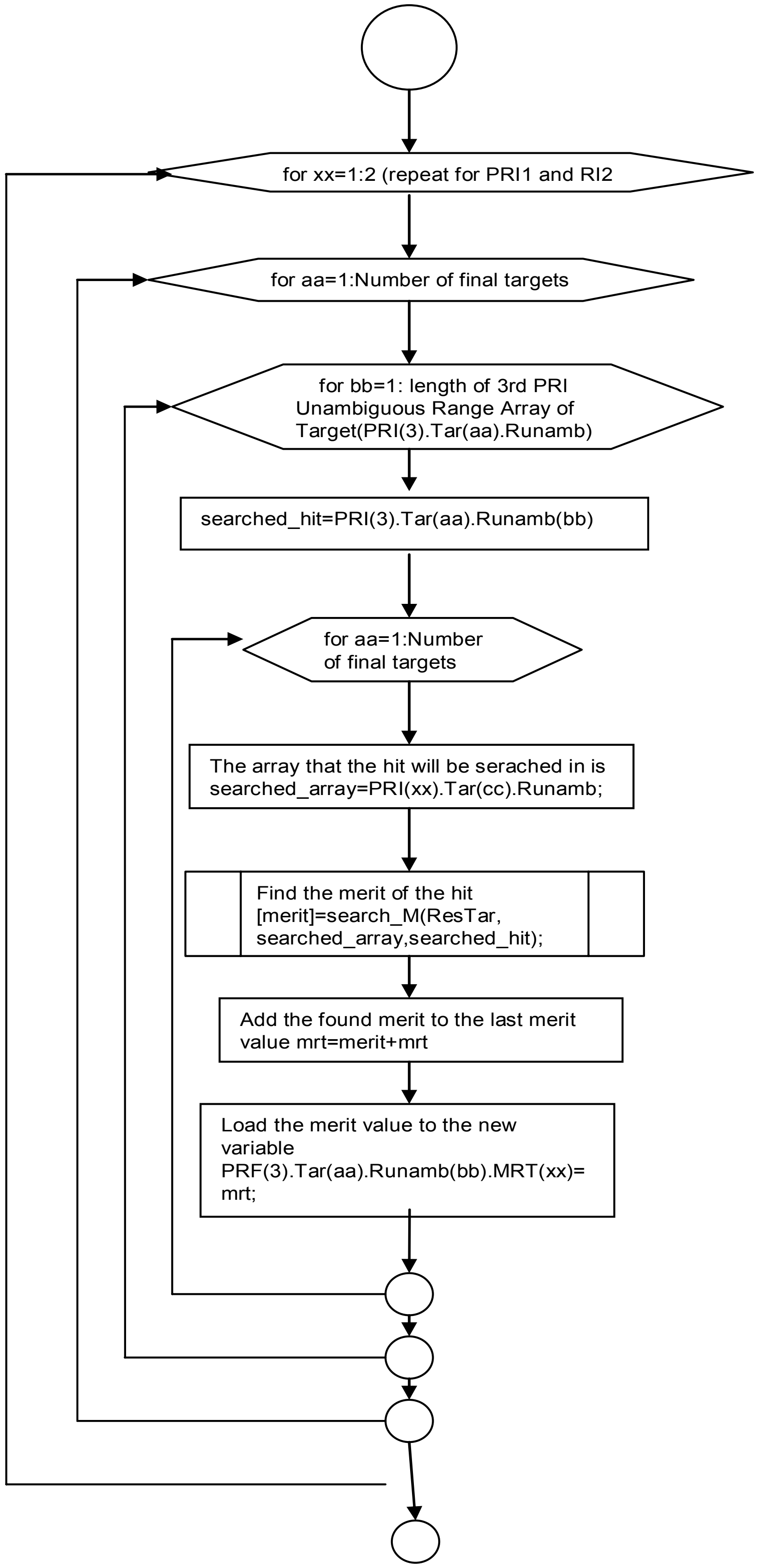

Figure B. 33 Merit Calculations Flow Chart

ADD THE MERITS AND DECIDE THE SELECTION OF HIT ;TRUE OR FALSE

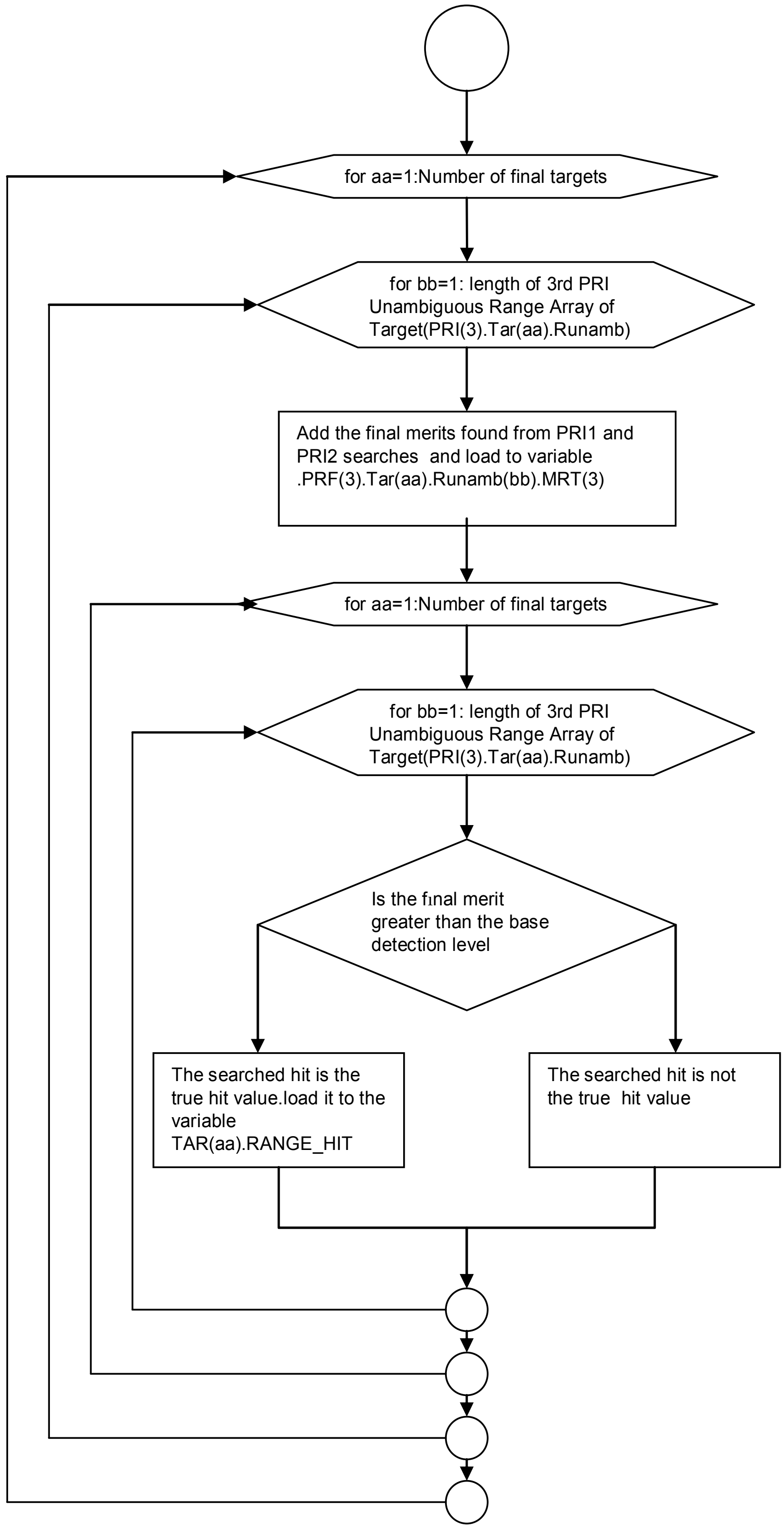

Figure B. 34 Hit Detection and Decisions Flow Chart

VELOCITY CALCULATIONS

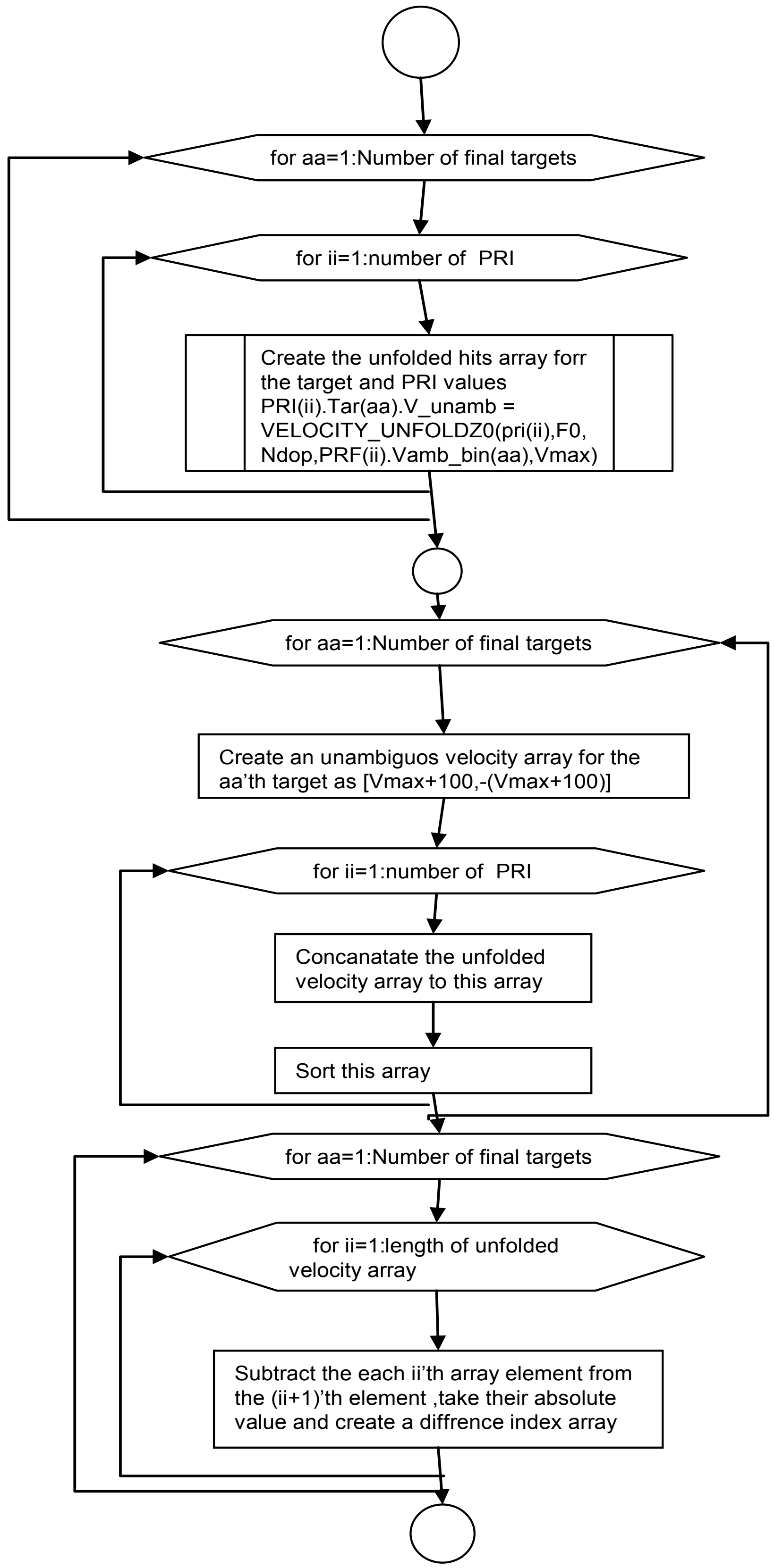

Figure B. 35 Velocity Calculations Flow Chart

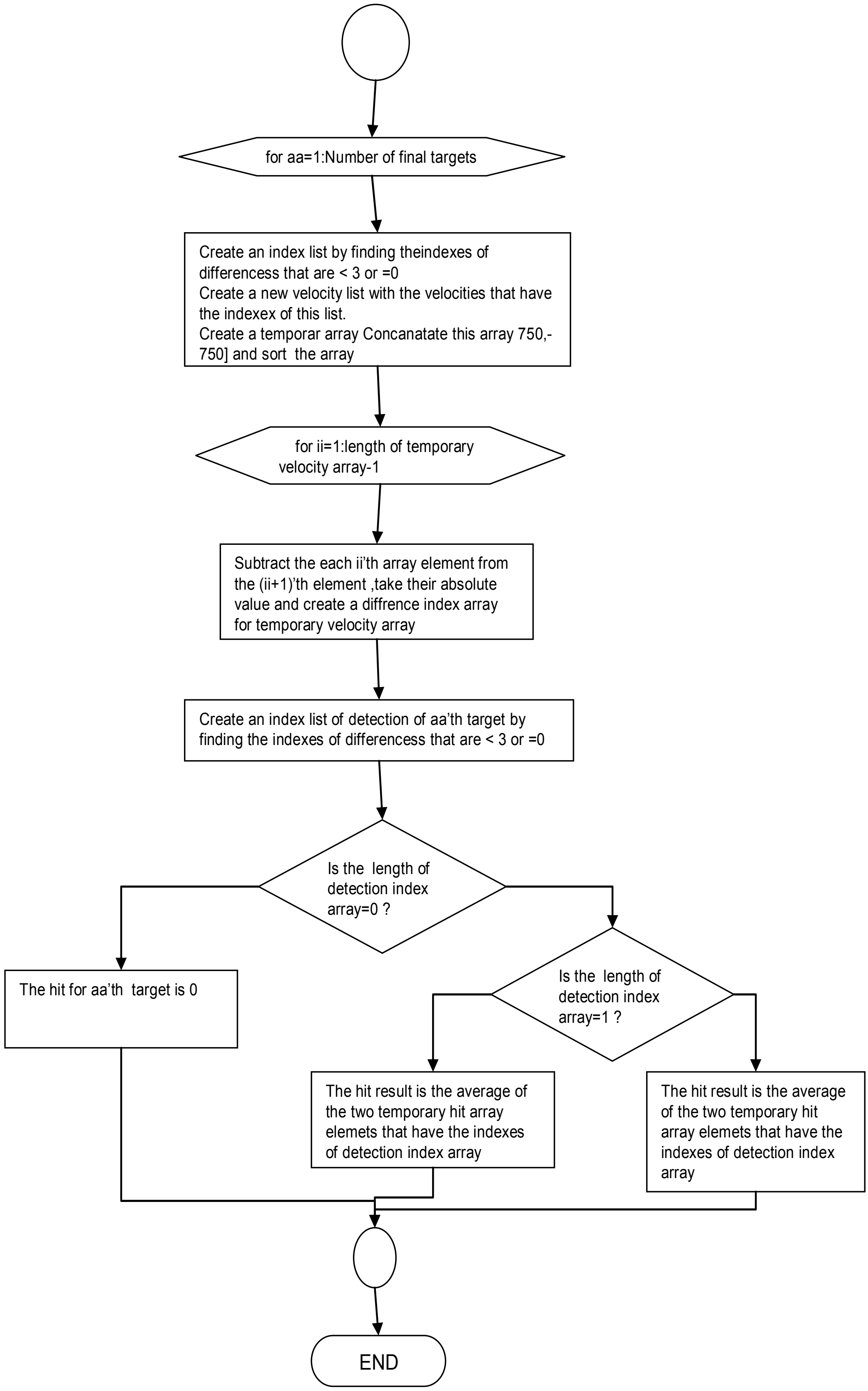

Figure B. 36 Velocity Hit Decision Flow Chart

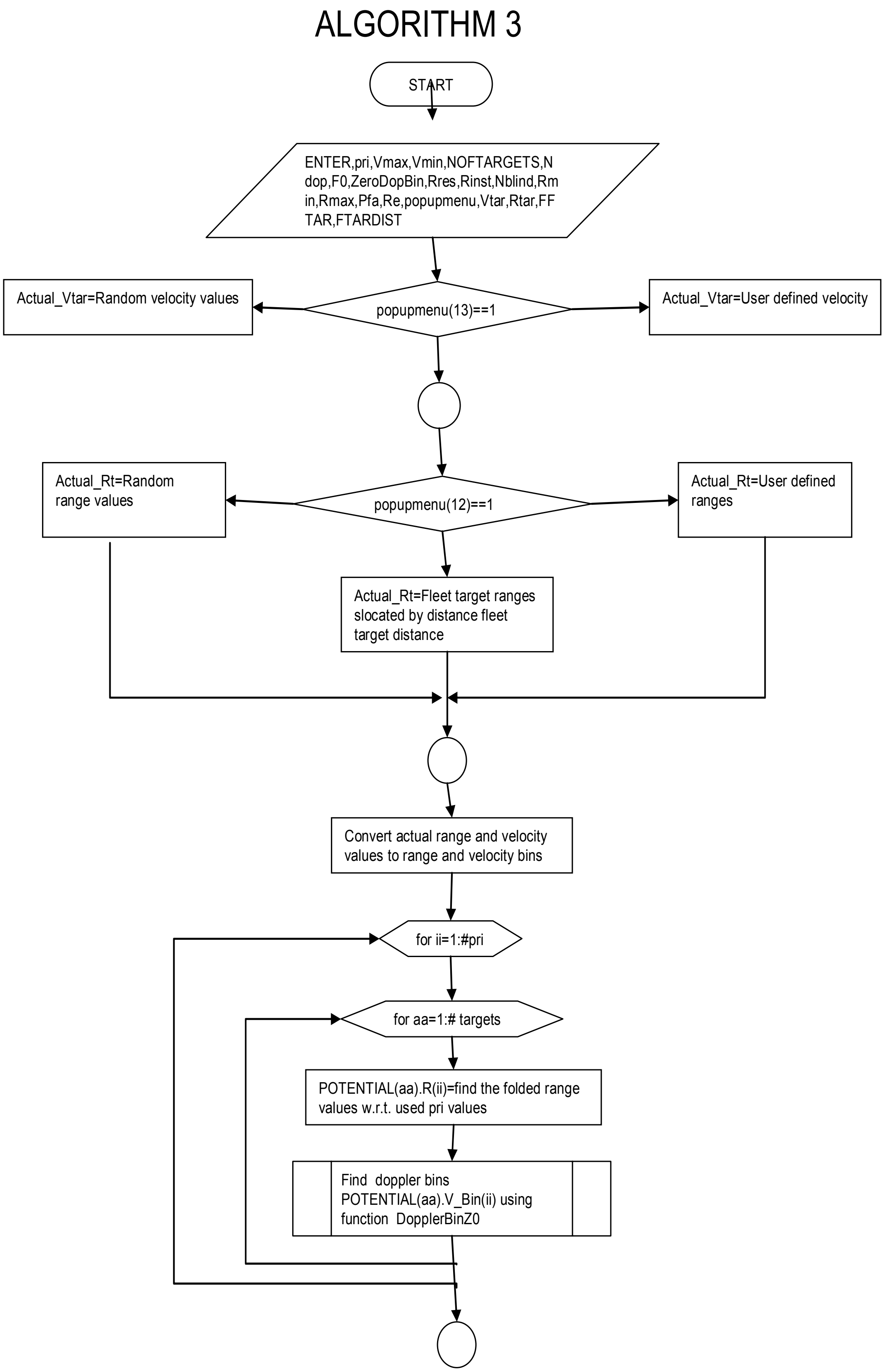

Figure B. 37 Algorithm 3 Flow Chart

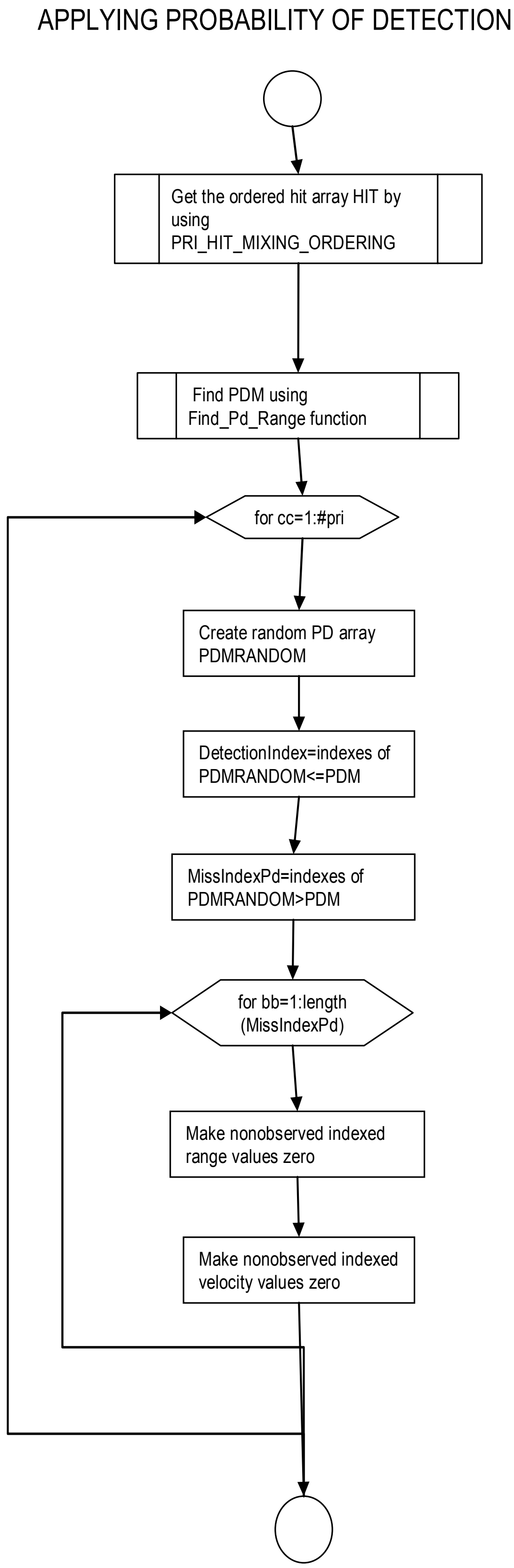

Figure B. 38 Appliying Probability of Detection Flow Chart

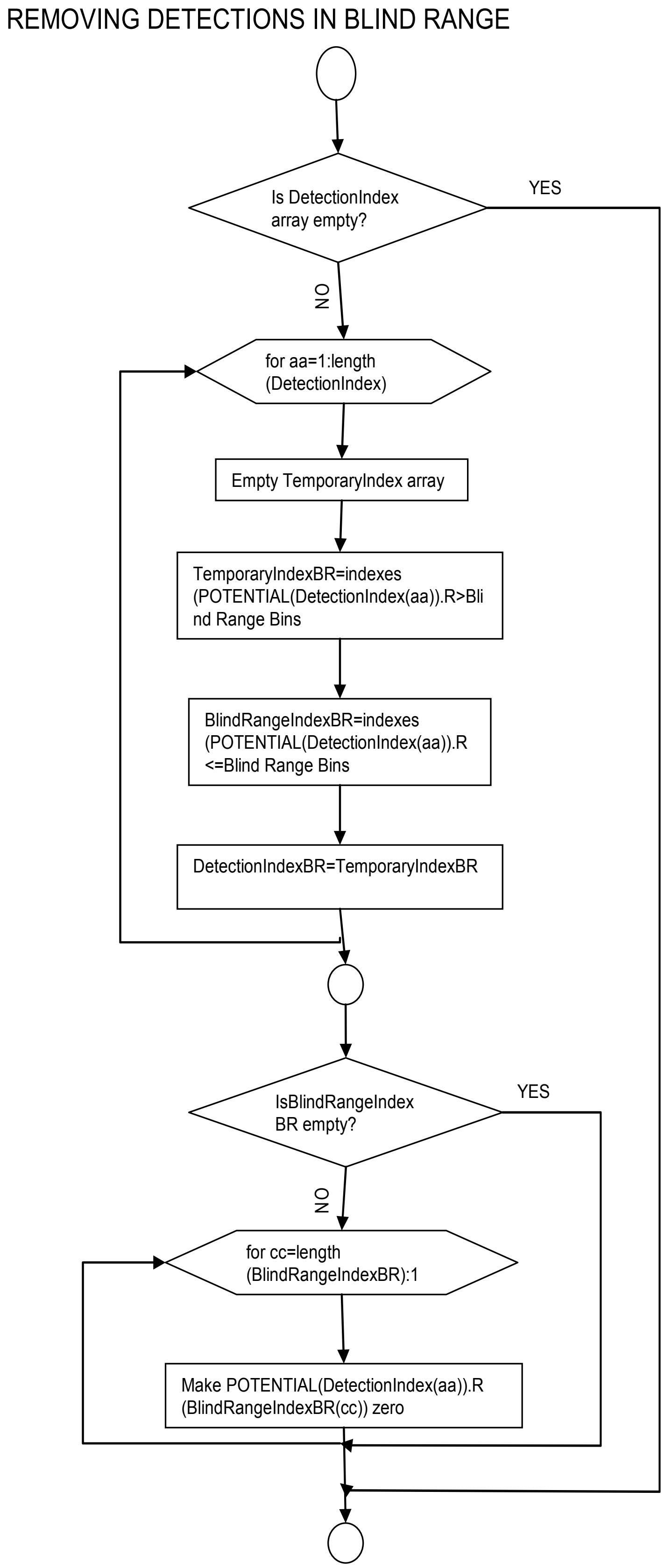

Figure B. 39 Removing Detections in Blind Range Flow Chart

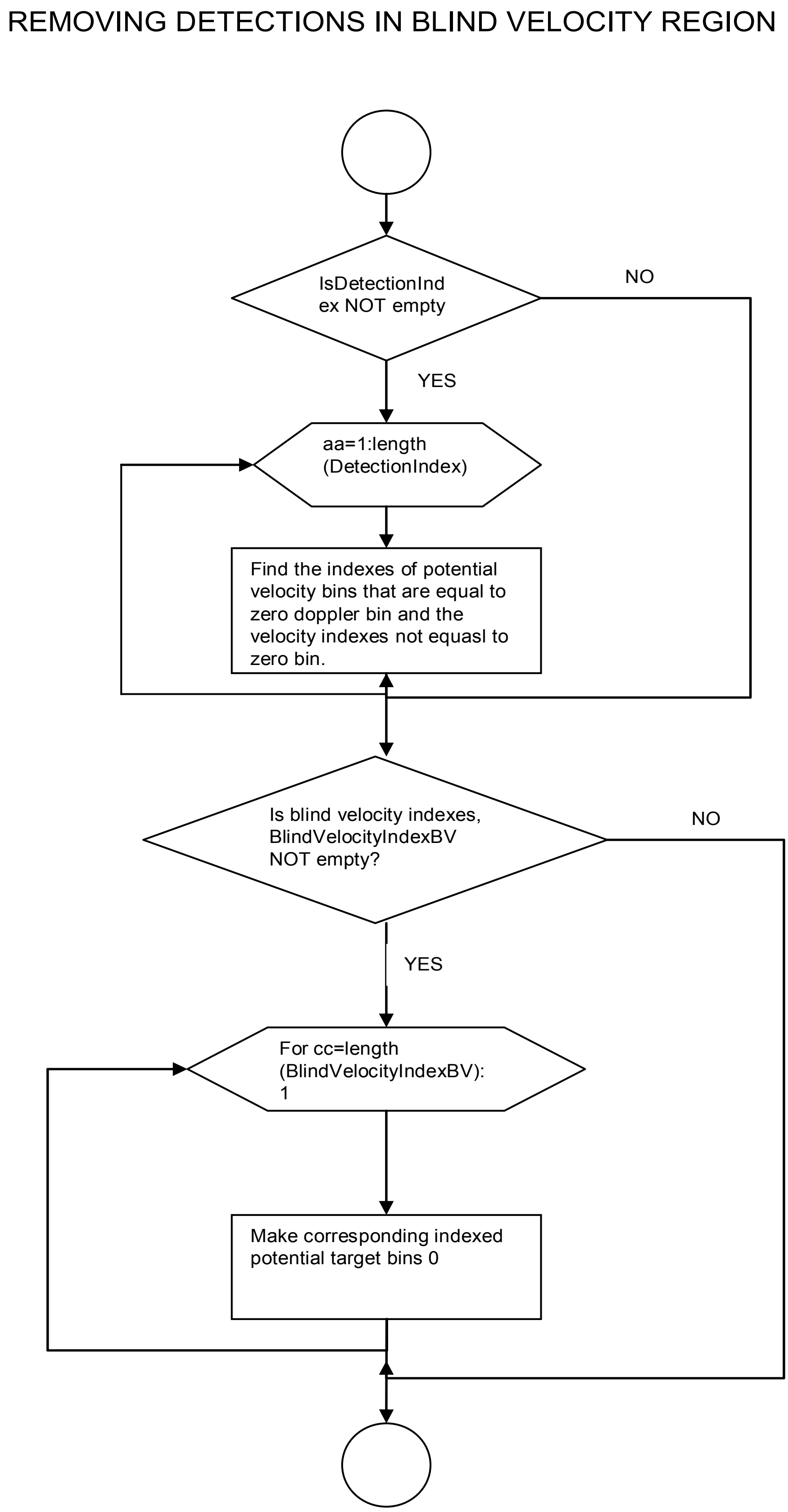

Figure B. 40 Removing Detections in Blind Velocity Region Flow Chart

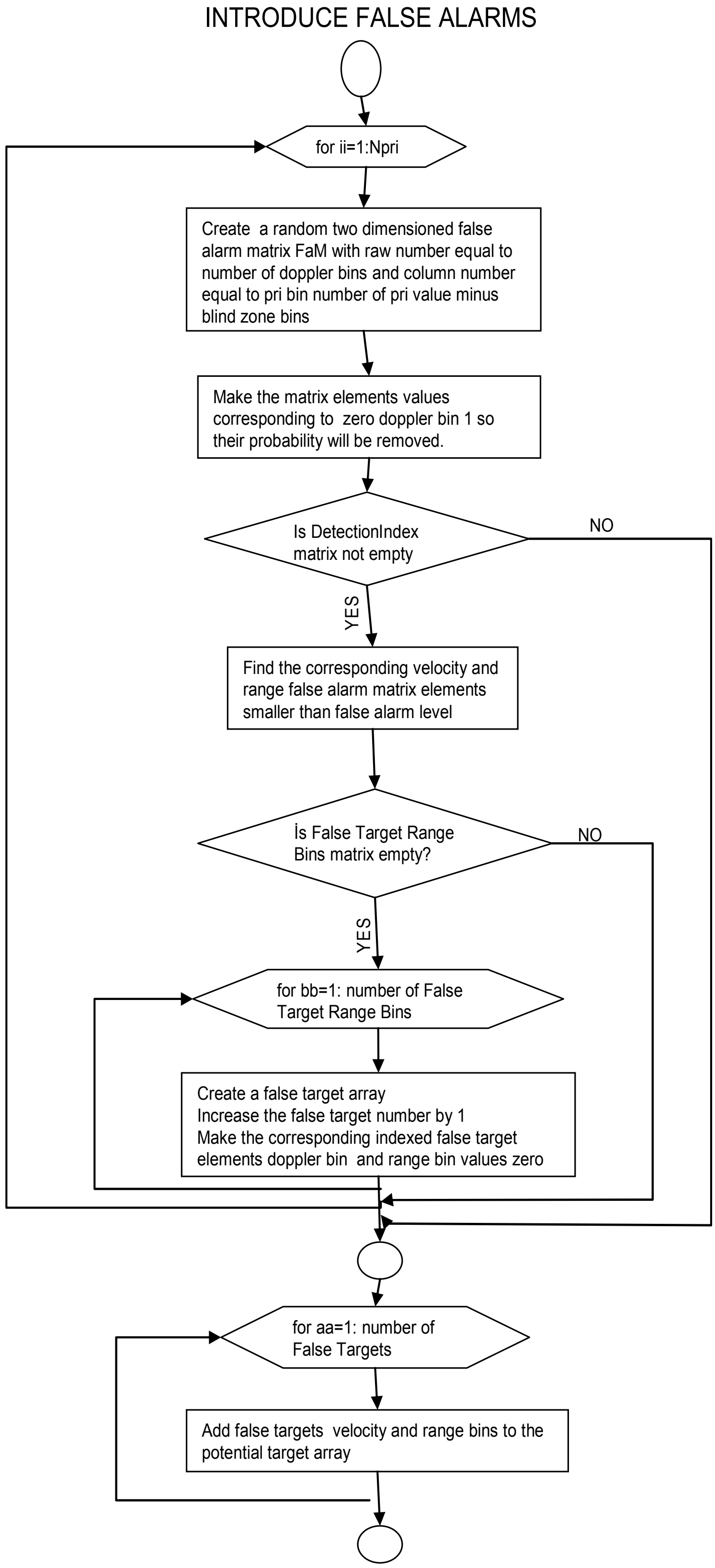

Figure B. 41 Introduce False Alarms Flow Chart

UNFOLDING THE AMBIGUOUS RANGES

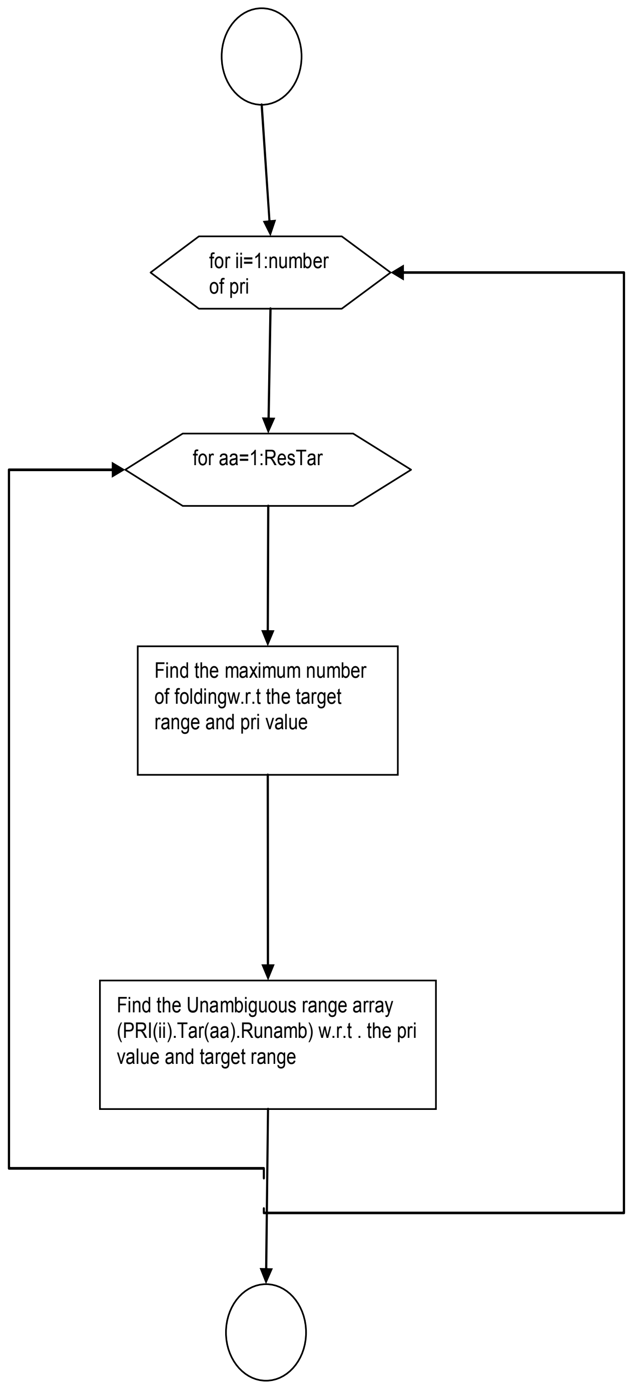

Figure B. 42 Unfolding The Ambiguous Ranges Flow Chart

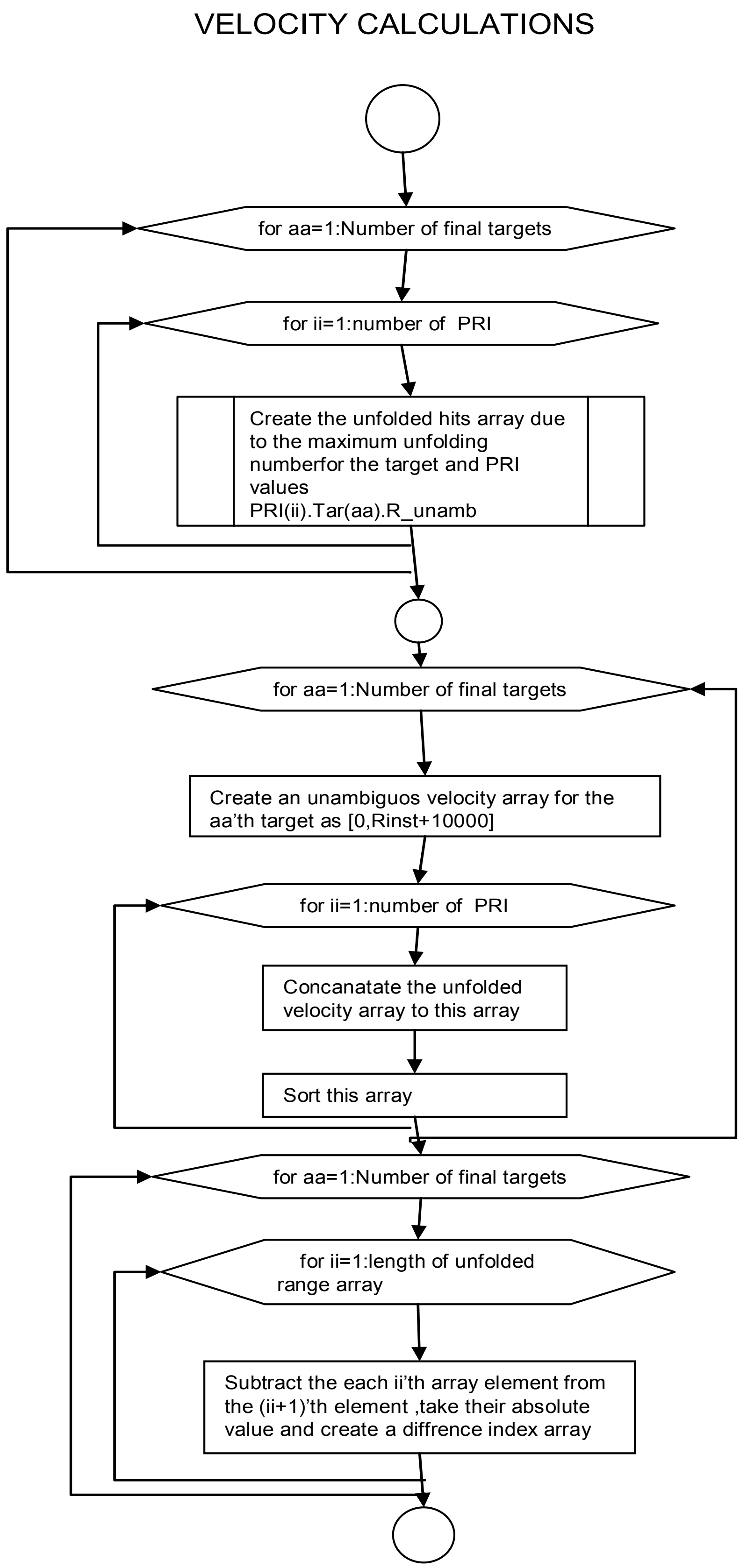

Figure B. 43 Velocity Calculations Flow Chart

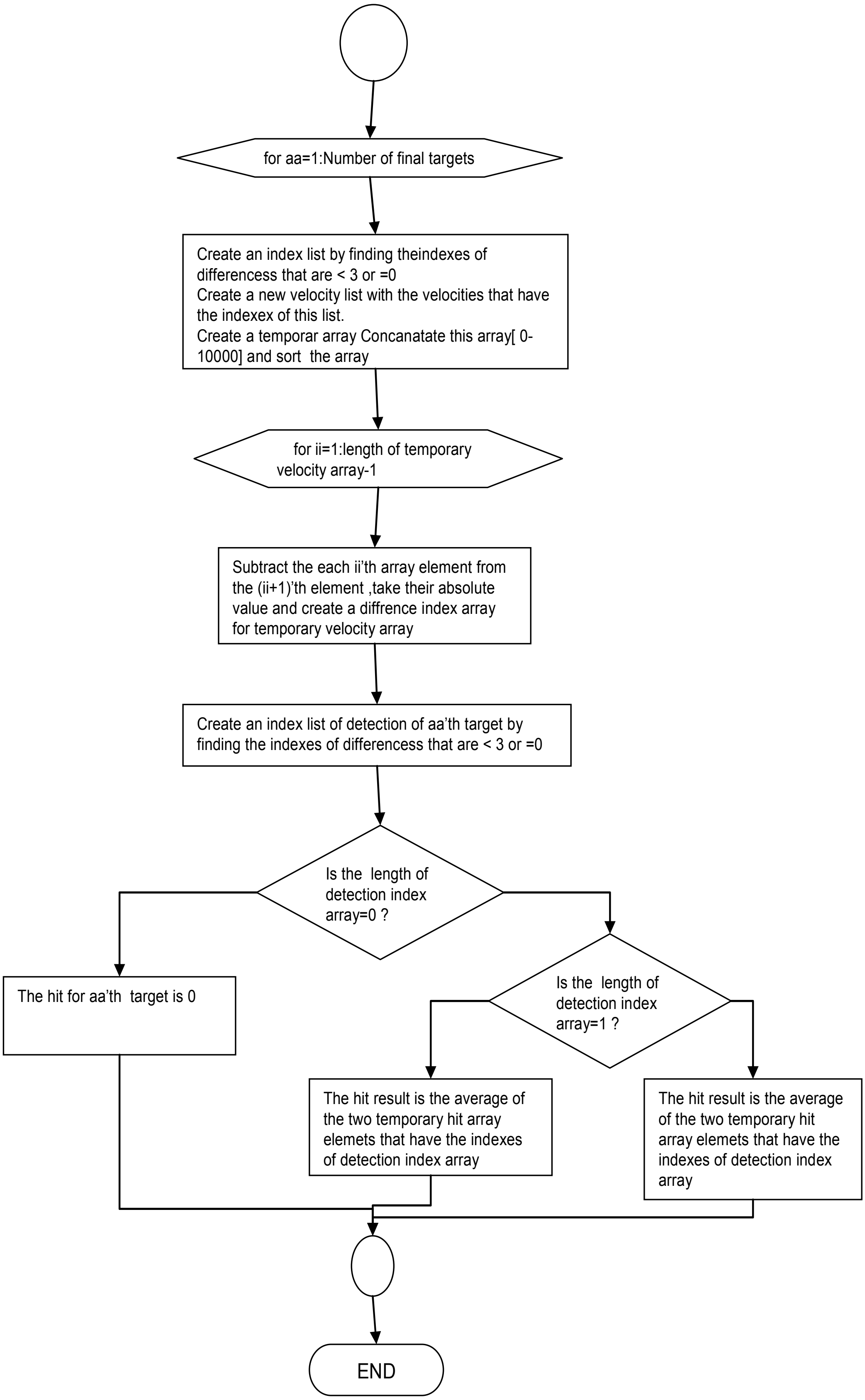

Figure B. 44 Velocity Hit Decisions Flow Chart

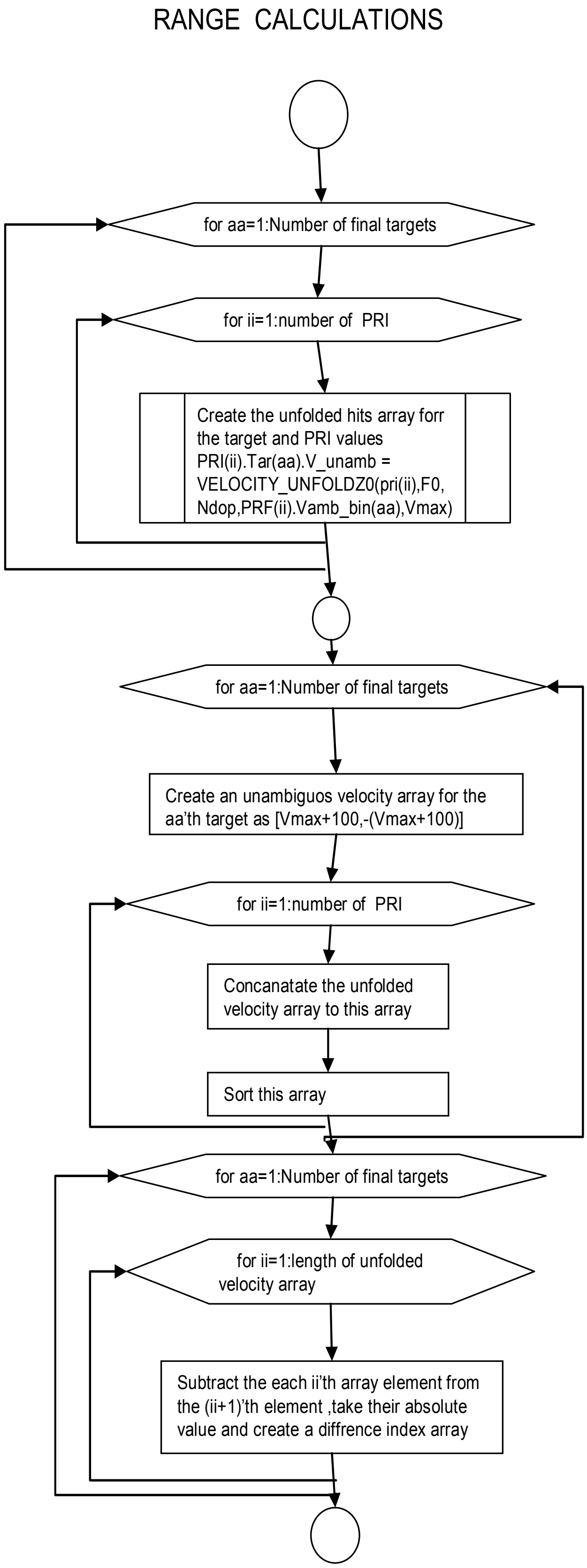

Figure B. 45 Range Calculations Flow Chart

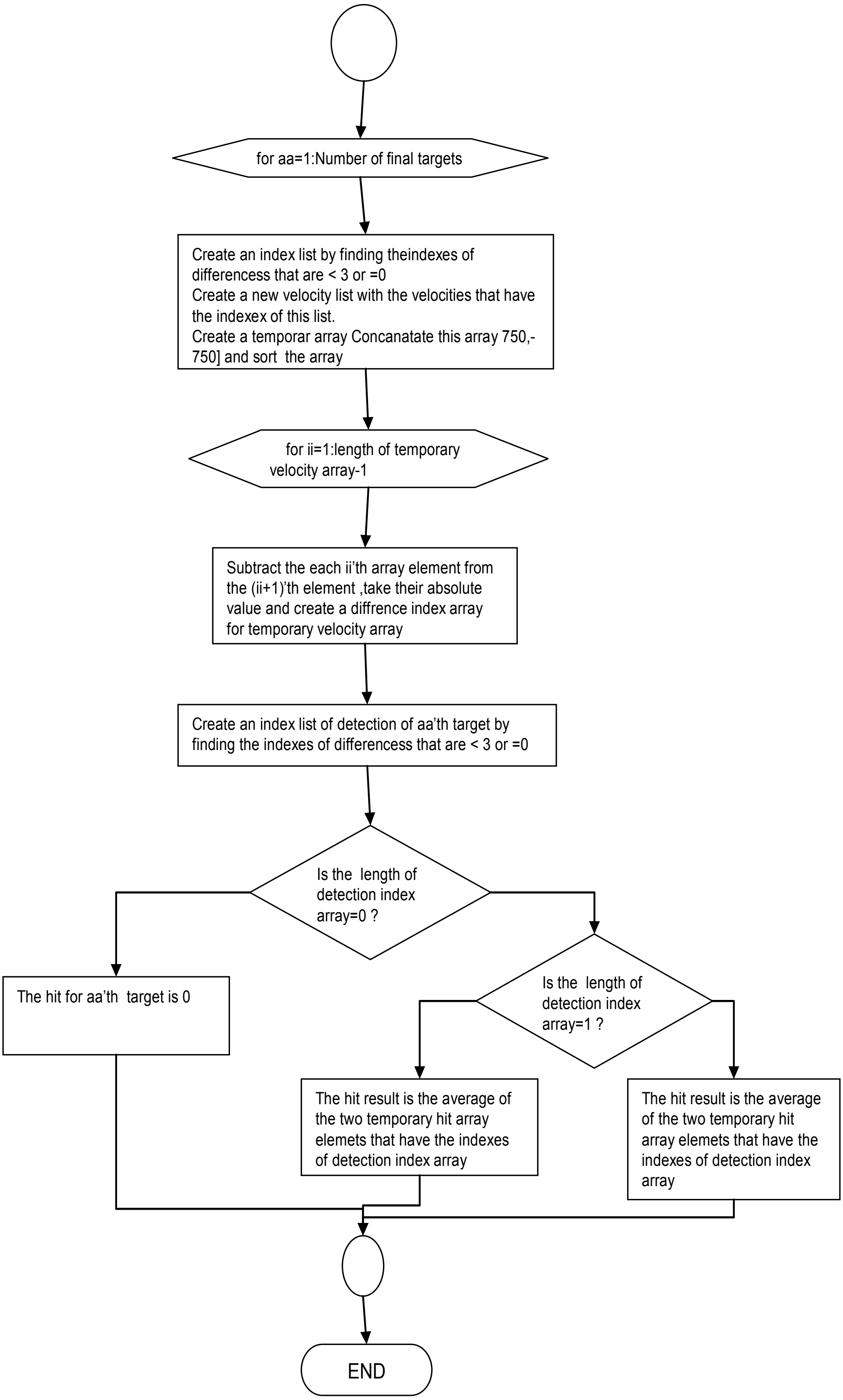

Figure B. 46 Range Hit Decisions Flow Chart

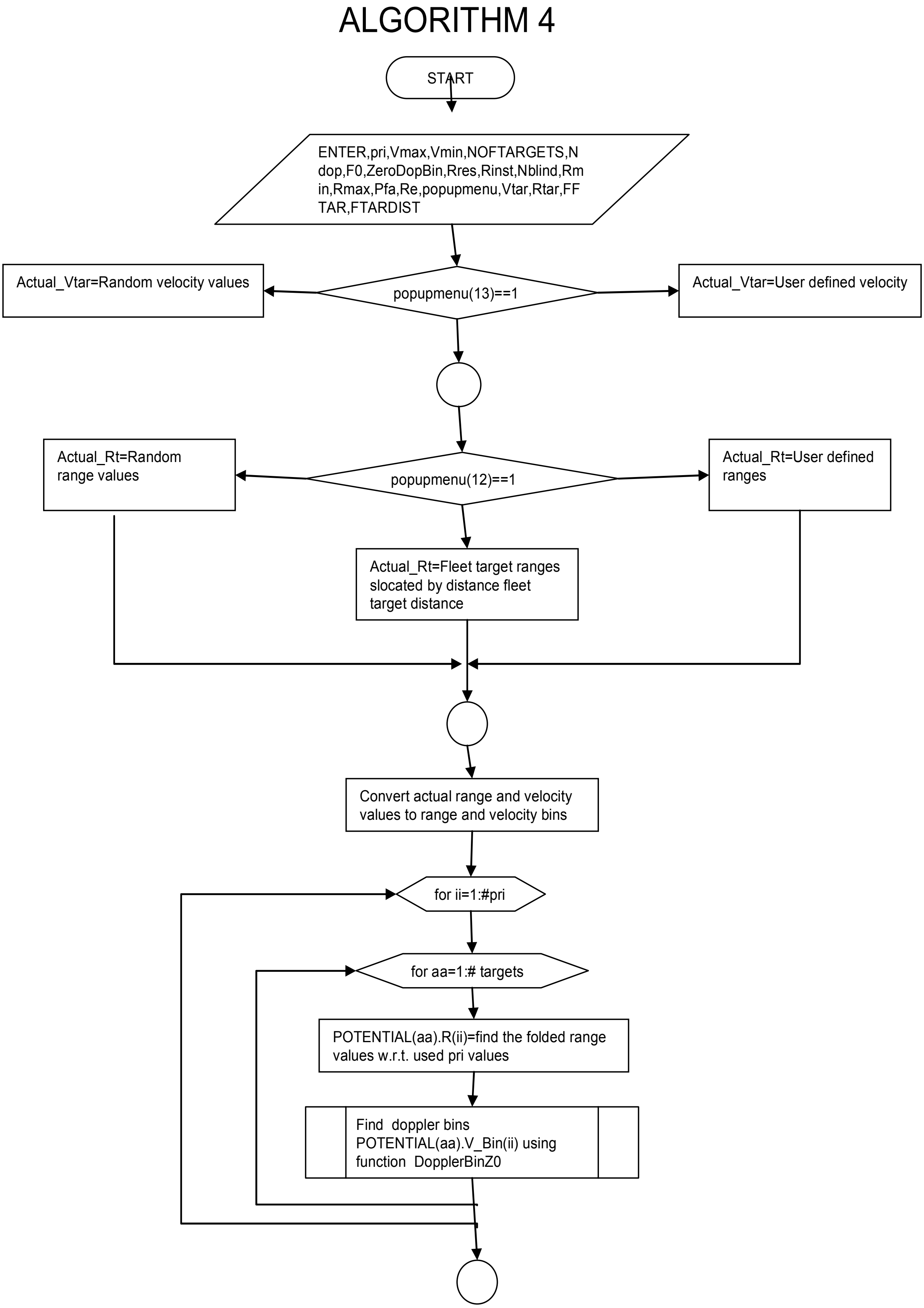

Figure B. 47 Algorithm 4 Flow Chart

APPLYING PROBABILITY OF DETECTION

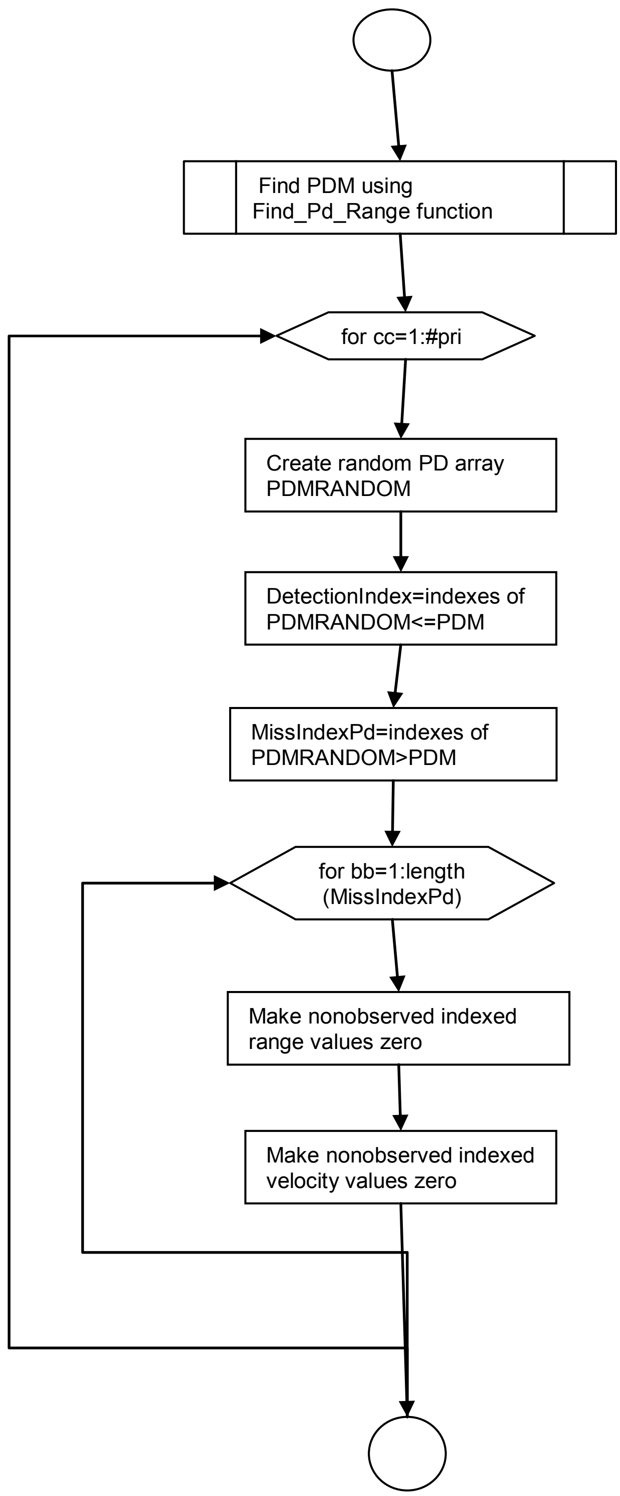

Figure B. 48 Applying Probability of Detection Flow Chart

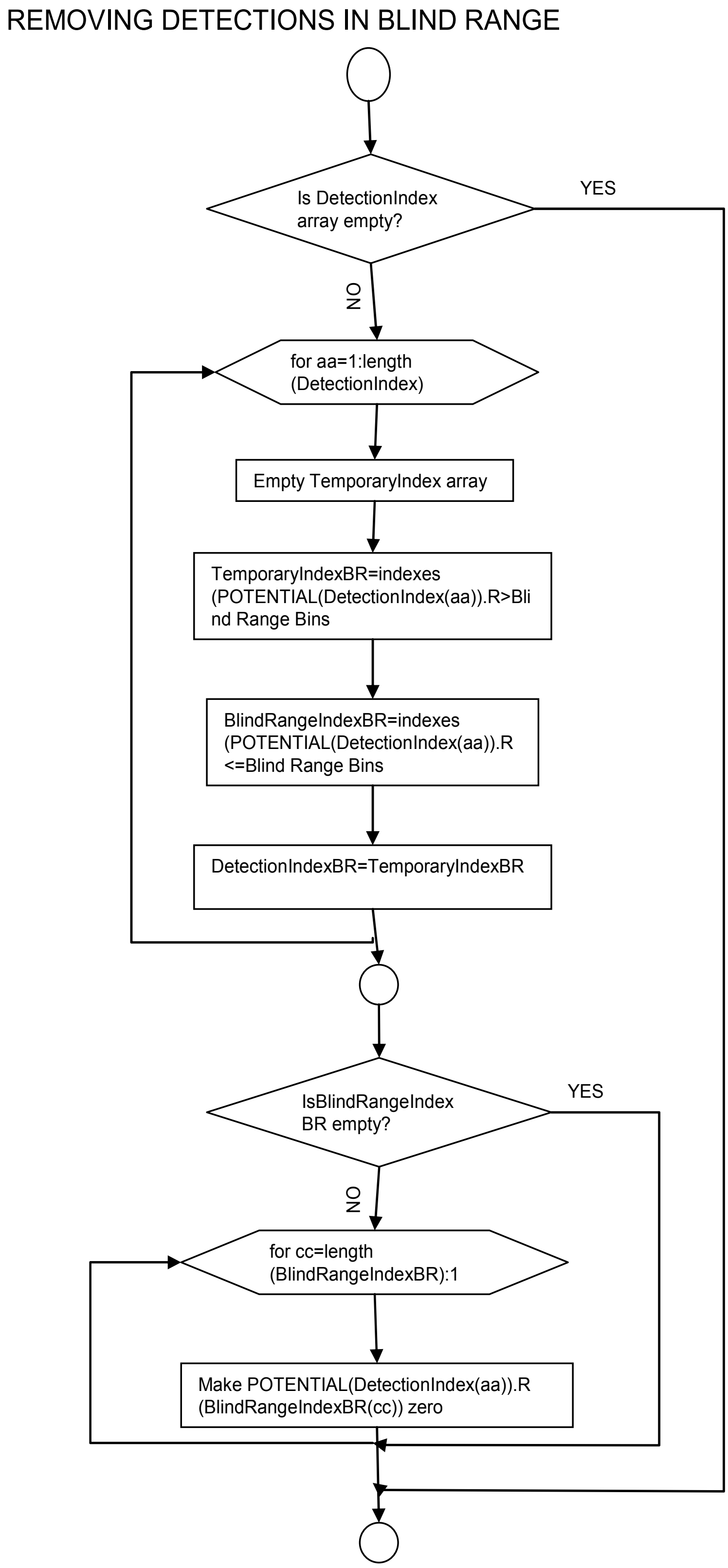

Figure B. 49 Removing Detections in Blind Range Flow Chart

REMOVING DETECTIONS IN BLIND VELOCITY REGION

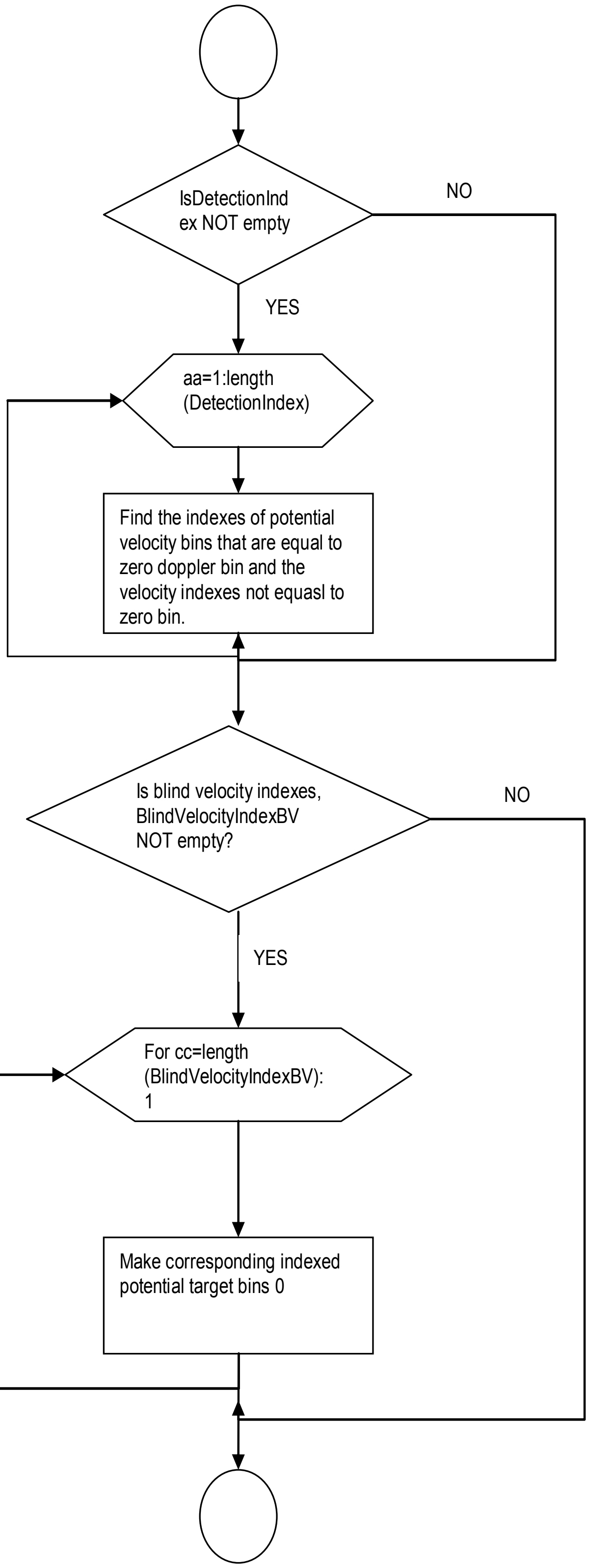

Figure B. 50 Removing Detections in Blind Velocity Region Flow Chart

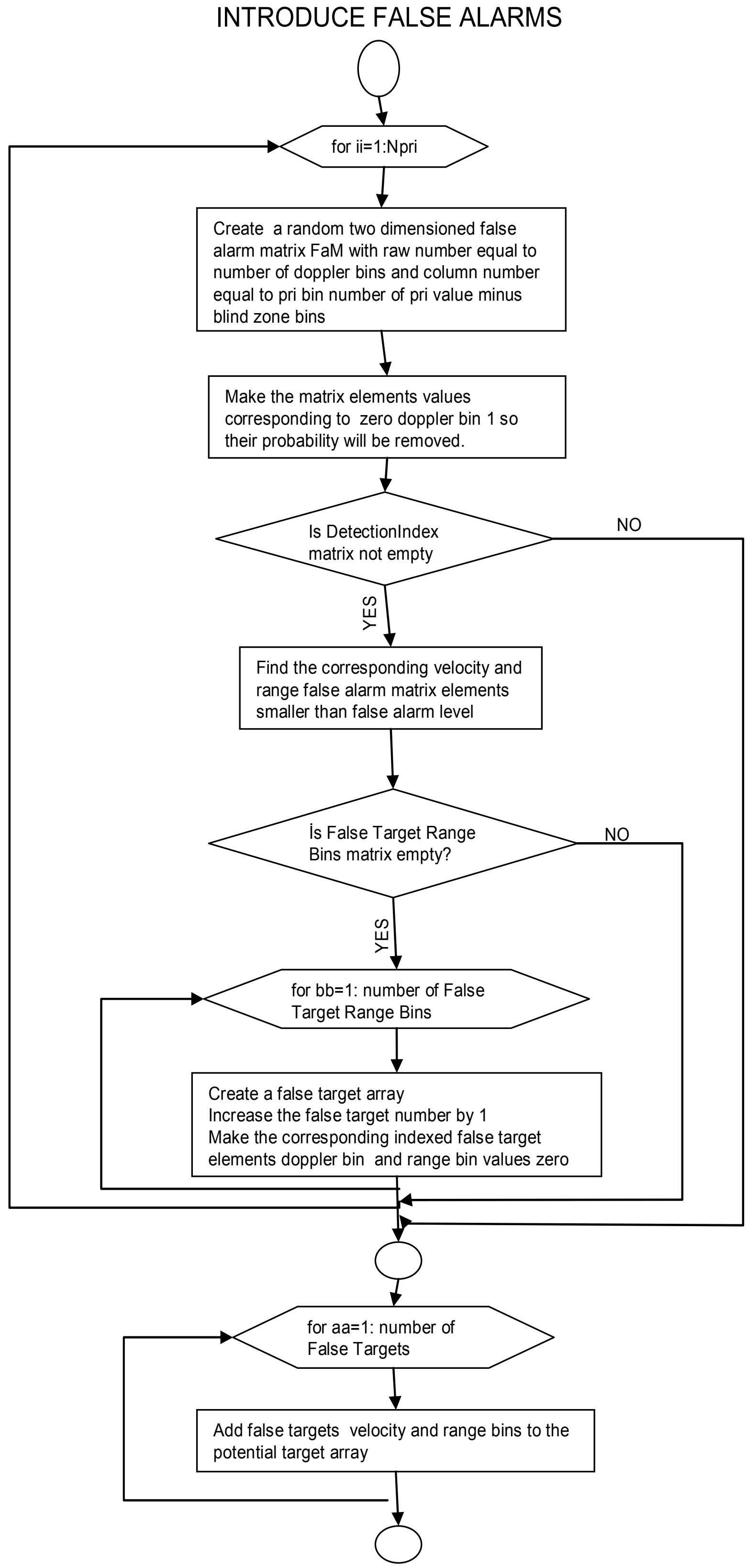

Figure B. 51Introduce False Alarms Flow Chart

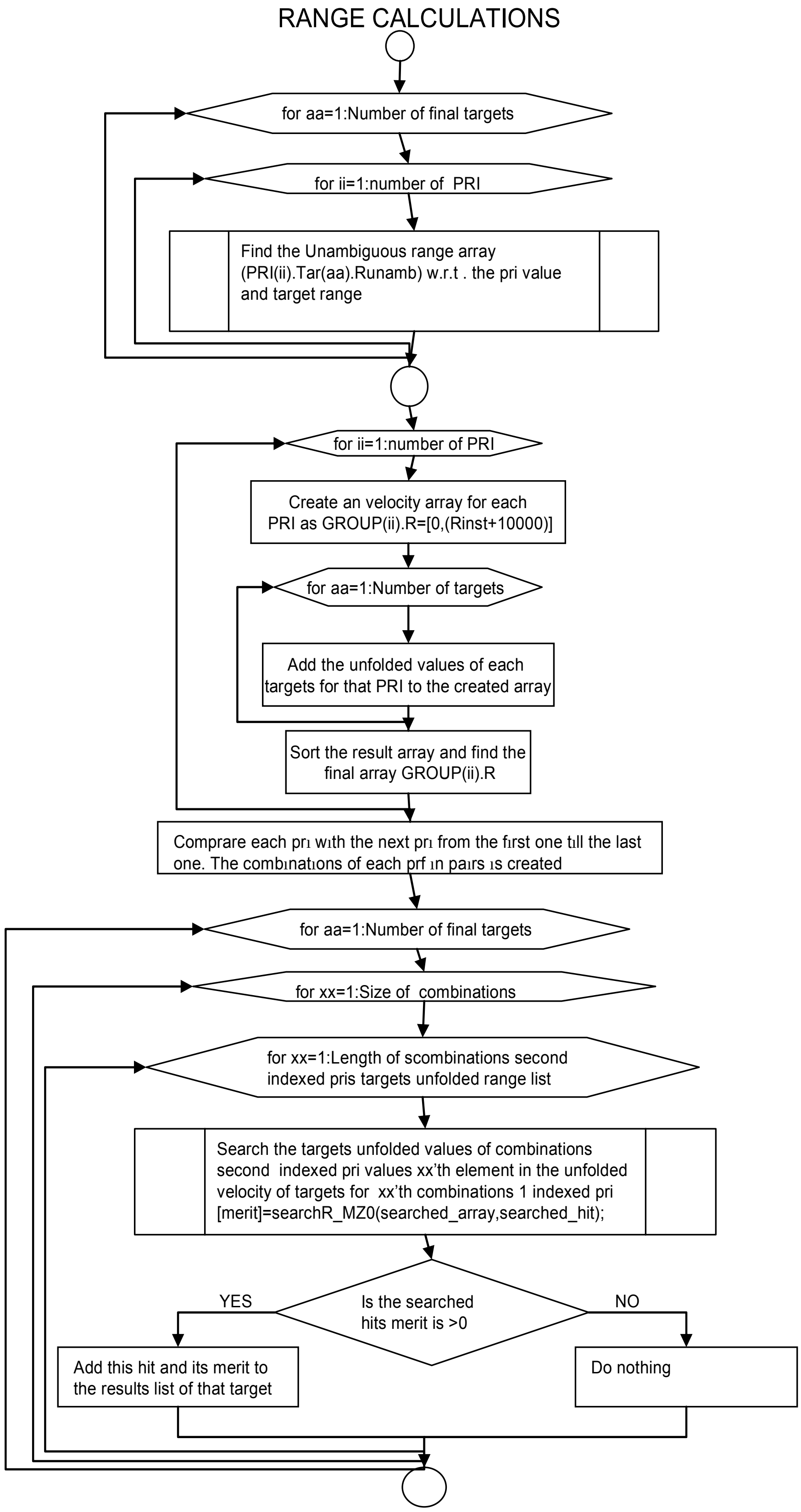

Figure B. 52 Range Calculations Flow Chart

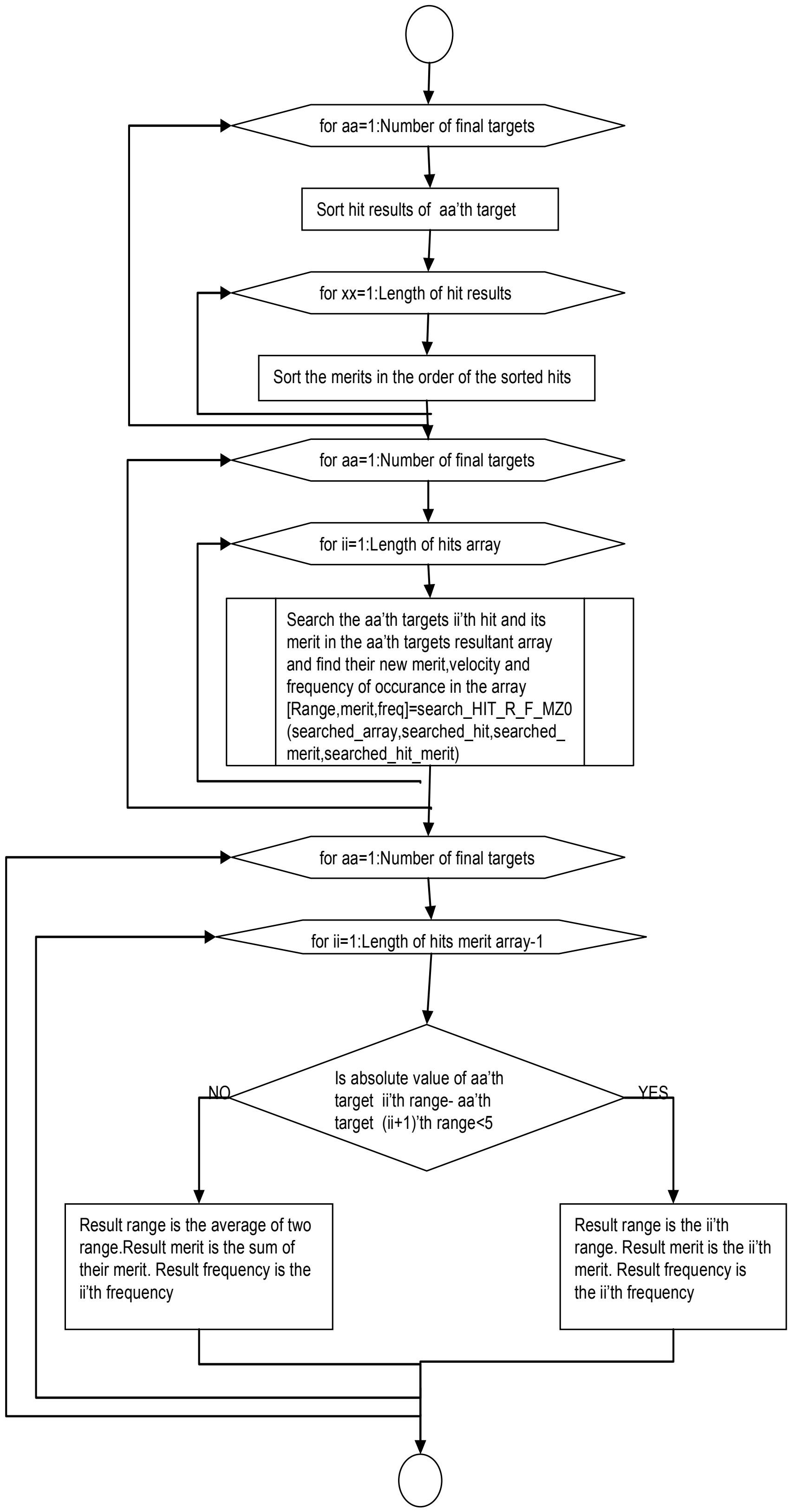

Figure B. 53 Merit Calculations Flow Chart

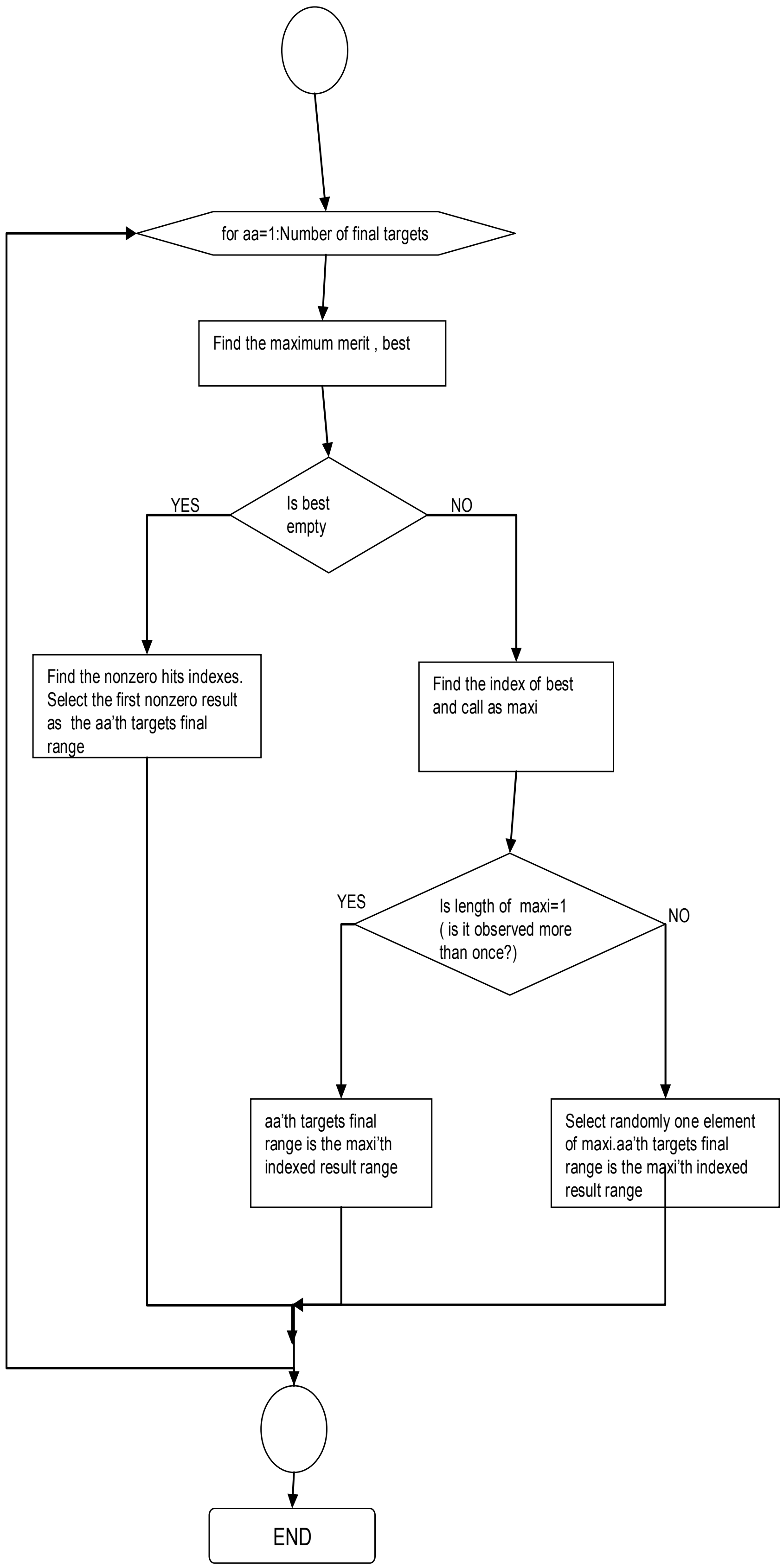

Figure B. 54 Range Hit Decisions Flow Chart

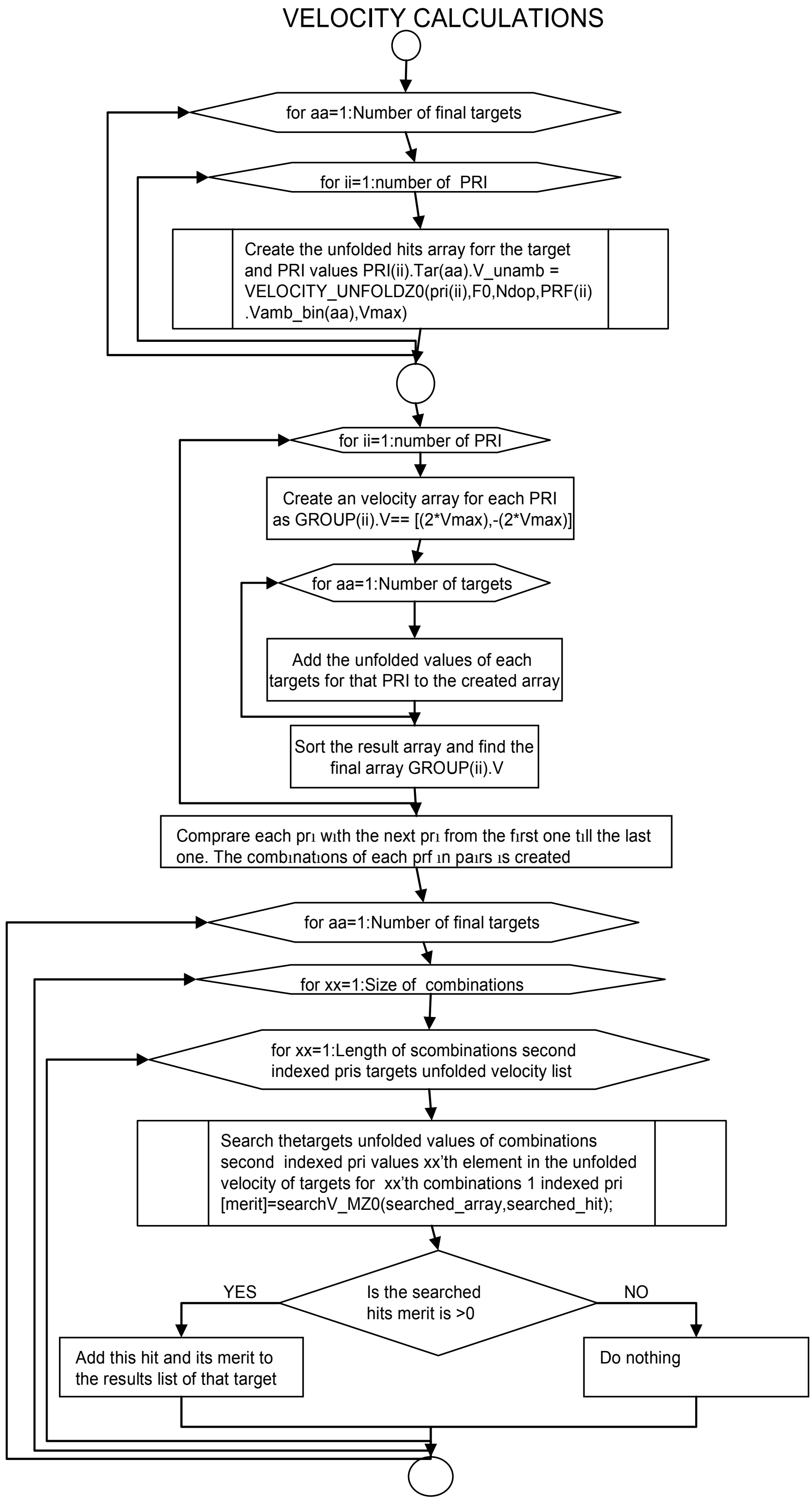

Figure B. 55 Velocity Calculations Flow Chart

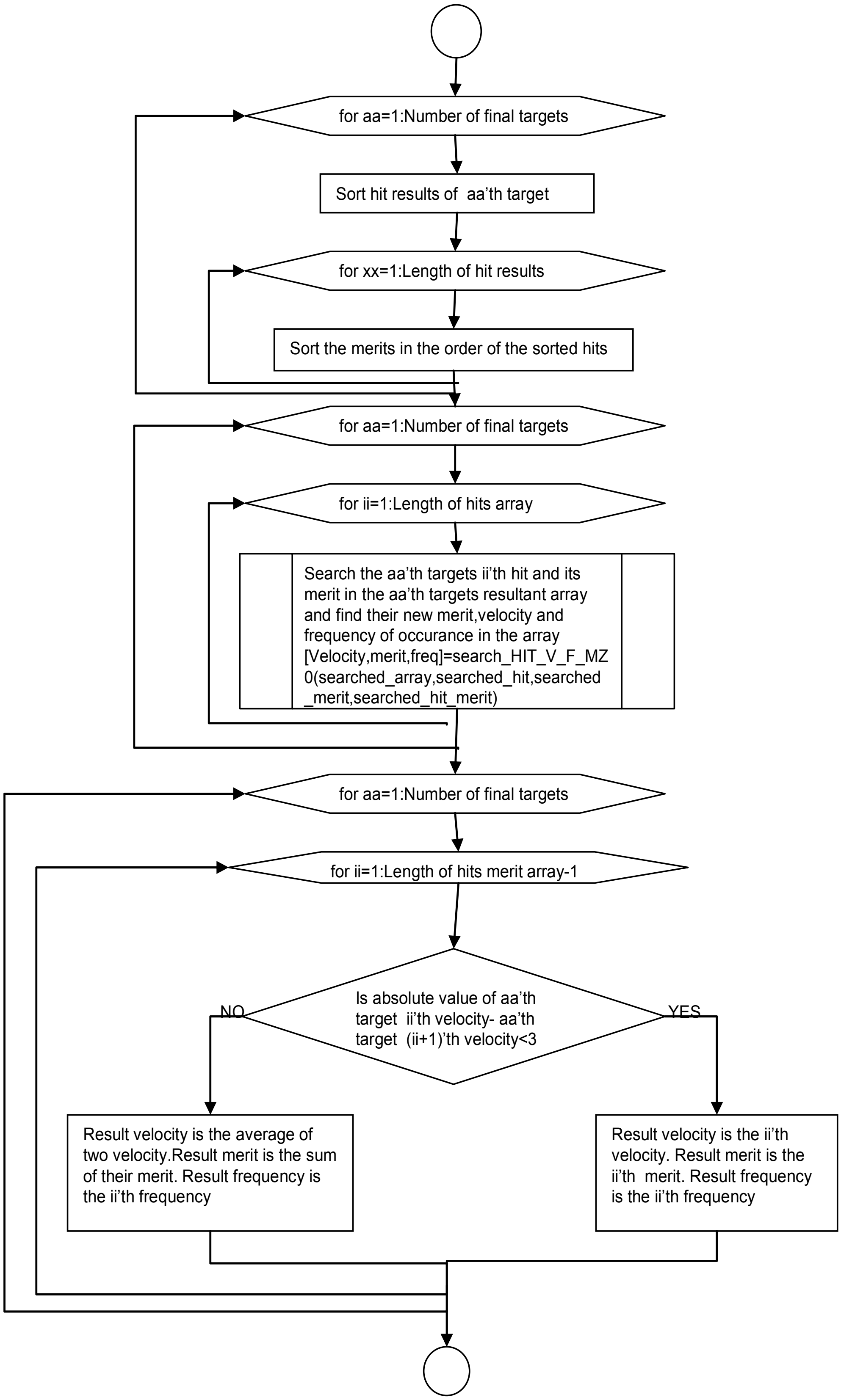

Figure B. 56 Velocity Hit Decision Flow Chart