CHAPTER 4 FORMULATION OF PROBLEM AND SOLUTIONS

4.1 PROBLEM DEFINITION:

The generic definition of the problem is detection of the target of interest is an object which is ship against the background which is affected by clutter generated by Natural elements, Manmade elements and Environmental elements. This problem is further complicated by the noise induced in the acquisition of data, pre-processing and processing by analysis tools. The detection cycle of any target detection problem has the following stage:-

(i) Selection of region of interest.

(ii) Detection of target

(iii) Recognition of target

(iv) Identification of target

4.2 MATHEMATICAL DEFINITION:

Fundamentally, the ship detection is a binary decision problem Binary decision problem who decision variable (L) is above a detection threshold (η) for given False Alarm (FA) to satisfy the following hypothesis:

(i) H1: Alternate hypothesis (ship)

(ii) H0: Null hypothesis (ocean/water)

Alternatively, the ship detection is to find the potential ship pixels amongst the background ocean/water pixels which is defined by a parameter of the input image which is called a decision variable subject to threshold to ensure detection of ships for a given False Alarm (FA).

In accordance to statistical decision theory, using likelihood ratio test with the Neyman-Pearson criterion(Lin et. al, 2005), this decision variable (L) is the ratio of ship to ocean probability density function (PDF) assuming Gaussian distribution of scattering components for ships & ocean; greater than a detection threshold (η) for given Probability of False Alarm (PFA). Then the other parameters that define the detection performance can be further deduced as follows:

(i) Probability of Missed Detection (PMD) = 1 - Nd/Ns where Nd is detected pixels out of Ns ship samples.

(ii) Probability of False Alarm (PFA) = Nfa/No where Nfa is no. of false alarm pixels out of No ocean samples.

(iii) Probability of detection (PD) = Nd/Ns which implies PMD = 1 - PD

(iv) Receiver operating characteristics (ROC) can be assessed by plotting PMD (Detection Efficiency) vs PFA for various detection threshold (η).

4.3 EXISTING METHODS:

All the methods of ship detection aim at providing the best detection probability of Detection or Detection probability (PD) with reduced or low Probability of Missed detection (PMD) while attempting to do the whole process in a computationally efficient manner. But the irony is that all the attempts based on the threshold of the decision variable to suit this ideal requirement of algorithm is conflicting and hence needs a tradeoff unless a better decision strategy is formulated. The various existing decision strategies are listed.

4.3.1 BASED ON THE DETECTION STRATEGY:

(i) Background analysis: In this the background is assumed to be homogenous scattering and any deviation in this mechanism is detected as an anomaly to delineate the target. This kind of strategies have worked very well in some of the demonstrated work by military analysis labs to exploit the potential in detection of submarines, debris and under water vessels. However this approach is useful under calm sea conditions for detection and in most cases renders it unusable. Conventional back scatter based algorithms [7-8], CFAR (Constant False Alarm Rate) and RCS (Radar cross section) based algorithms fall under this approach.

(ii) Target and Background analysis: This approach aims to provide an ideal scenario for the ship detection as the discrimination between the target and background by characterisation of the back scatter or polarimetric signatures of both target and background as well. Extended CFAR, Rice Factor based [4], polarisation based algorithms fall under this approach.

4.3.2 BASED ON THE FEATURE USED AS THE DECISION VARIABLE:

(i) Point feature or pixel based target analysis: In this approach, the pixel brightness obtained as a scattering component or RCS or Sigma naught or intensity of each pixel is analysed as a point feature. In these methods, parallel programming can be used to accelerate the analysis as the decision criteria does not depend on the previous analysis on the neighboring pixel. Often this approach is dependent on the probability density function of decision variable for given background or target, which is decided by the detection threshold. Hence as the threshold reduces both PFA and PD increases. Typical Likelihood Ratio Test (LRT) and RCS based approaches fall under this category.

(ii) Area based target analysis: In this analysis, the target with reference to the background is used to create parameters that control the False alarm. CFAR method although takes care only the background area, while the Extended CFAR method increases the adjacent pixel probability of belongingness for a stated threshold which decreases the PFA.

4.4 PROPOSED METHODOLOGY:

The proposed analysis method has properties of point, area and adjacency of the ship pixels against the background. This method ensures required PD with controlled PFA with optimised thresholding of the decision variable(s) for the ship detection problem. The methods of the proposed analysis are as follows:

(i) Point based: The algorithm starts the process of analysing the individual pixels by using a Support Vector Machine (SVM) based detection threshold optimisation of decision variables.

(ii) Area based: Raster analysis of clumping and sieving is used to establish the adjacency and thereafter reducing the false alarms by deciding the lower threshold of the target.

(iii) Adjacency based: Histogram frequency slicing method will introduce a semi-automatic classification on the sieved image to produce the classes with different quantifiable adjacency.

(iv) Semi-empirical model based: The classification strategy is based on a reduced model for the estimation of the Gross Tonnage which in turn is used to classify the various types of ships.

4.5 GENERIC MODEL FOR A TYPICAL SHIP DETECTION ALGORITHM:

This generic model for a typical ship detection algorithm deals with a satellite constellation with a systematic coverage of the medium resolution and capable of switching mode to desired fine resolution mode. In our case of RISAT-1 has a systematic coverage of MRS (Medium Resolution ScanSAR) mode and can be switched to any other mode in the current orbit or node or subsequent node as per payload programming. The developed algorithm was first tested with Sentinel-1A & TerraSARX data and then applied on the RISAT-1 data for finalisation of the analysis. Land/Sea masking is intentionally not applied as this could easily be applied with CartoDem ver 3 or AsterDem at any stage of the process.

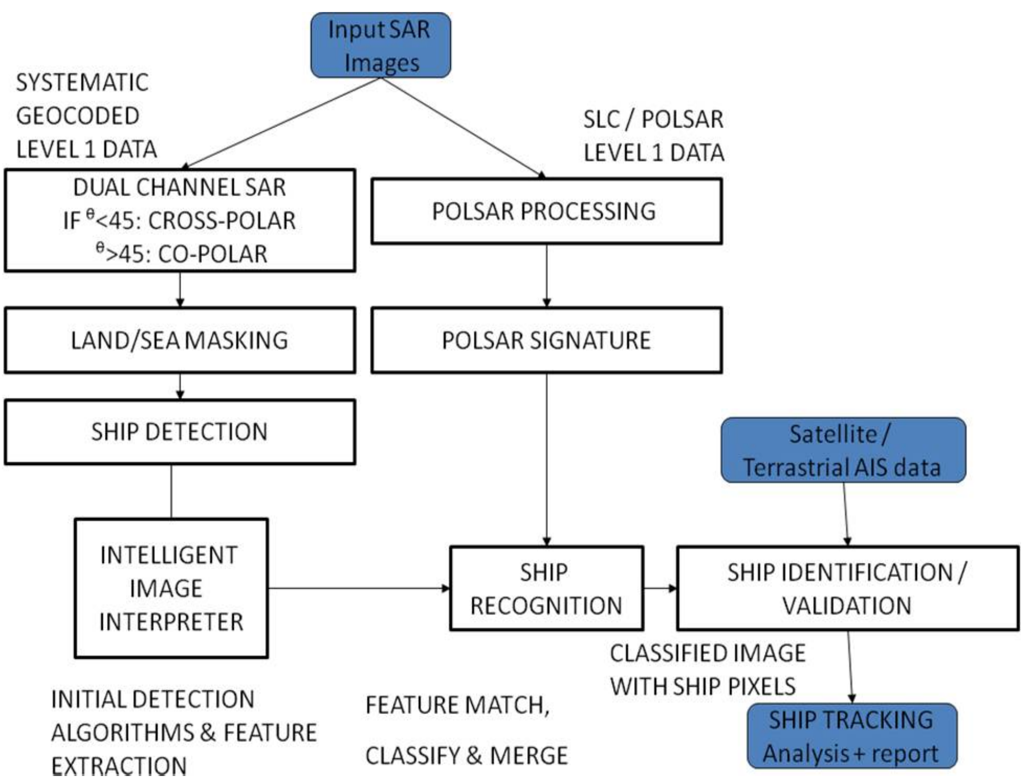

Figure 4.1: Generic model of Ship Detection Algorithm

4.6 INTELLIGENT IMAGE INTERPRETER:

4.6.1 SENTINEL-1A / RISAT-1 MRS PROCESSING:

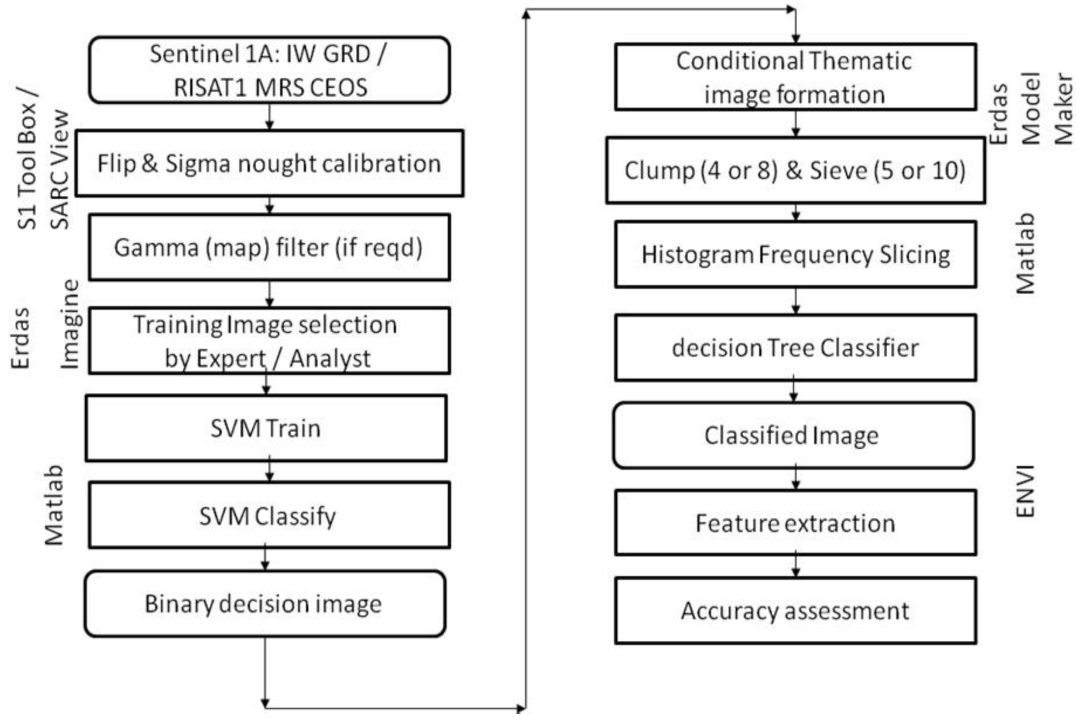

Figure 4.2: Methodology of Medium resolution data processing

4.6.2 SENTINEL-1A / RISAT-1 POLSAR PROCESSING:

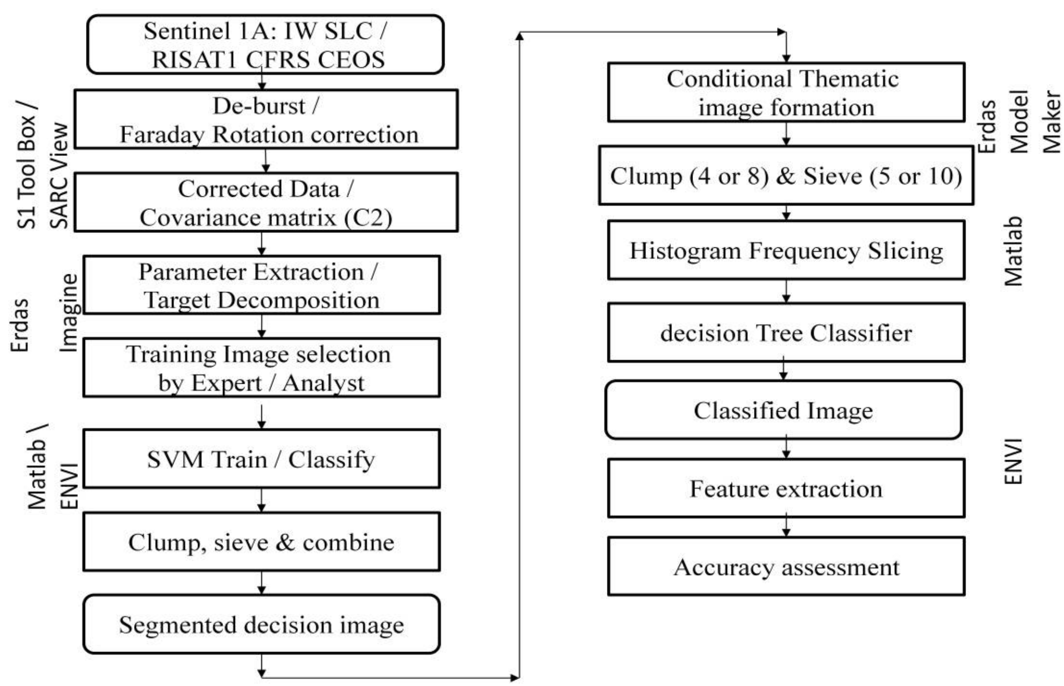

Figure 4.3: Methodology of Fine resolution SLC PolSAR Processing

Proposed PoLSAR Processing Technique:[4] Let the fully polarimetric scattering Sinclair matrix S be defined as

$$S = \begin{bmatrix} S_{\mathrm{HH}} & S_{\mathrm{VH}} \\ S_{\mathrm{HV}} & S_{\mathrm{VV}} \end{bmatrix} \qquad (4\text{-}1)$$

With the assumption of no noise and calibration errors, for any SAR mode the received matrix can be written as a function of S with Faraday Rotation (FR) angle Ω as

$$M = R_\Omega S R_\Omega \qquad \text{with} \quad R_\Omega = \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix} \qquad (4\text{-}2)$$

Let us consider the CTLR or pi/2 mode with Right hand circular polarisation transmission and coherent orthogonal linear reception represented in terms of the measured vector as

$$\vec{k} = \begin{pmatrix} k_1 \\ k_2 \end{pmatrix} = \frac{1}{\sqrt{2}} M \begin{pmatrix} 1 \\ -j \end{pmatrix}. \qquad (4\text{-}3)$$

With the first assumption of the reflection symmetry, which deduces that the cross and co-polar scattering co-efficient are not correlated.

$$\langle S_{\mathrm{HH}} S^*_{\mathrm{HV}} \rangle \approx \langle S_{\mathrm{VV}} S^*_{\mathrm{HV}} \rangle \approx 0 \qquad (4\text{-}4)$$

With the second assumption of bare-surface which is true in case of the seas, deduces that phase angle between the co-polarised channels are close to zero.

$$\arg \langle S_{\mathrm{HH}} S^*_{\mathrm{VV}} \rangle \approx 0 \qquad (4\text{-}5)$$

Let us consider CTLR case which is represented in terms of the linear scattering co-efficient as

$$S_{\mathrm{RH}} = \frac{1}{\sqrt{2}}(S_{\mathrm{HH}} - jS_{\mathrm{VH}})$$
$$S_{\mathrm{RV}} = \frac{1}{\sqrt{2}}(S_{\mathrm{HV}} - jS_{\mathrm{VV}}). \qquad (4\text{-}6)$$

The following can be derived [4] and holds good for our area of interest:

(i) Faraday Rotation estimation

$$\Omega = \frac{1}{2}\arctan\left(2\frac{\mathrm{Re}\,(M_{\mathrm{RH}}M_{\mathrm{RV}}^{*})}{(\langle M_{\mathrm{RV}}M_{\mathrm{RV}}^{*}\rangle - \langle M_{\mathrm{RH}}M_{\mathrm{RH}}^{*}\rangle)}\right) \bmod \frac{\pi}{4} \qquad (4\text{-}7)$$

(ii) Faraday Rotation correction

$$\begin{pmatrix}\tilde{S}_{\mathrm{RH}}\\ \tilde{S}_{\mathrm{RV}}\end{pmatrix} = e^{j\Omega}\begin{pmatrix}\cos\Omega & -\sin\Omega\\ \sin\Omega & \cos\Omega\end{pmatrix}\begin{pmatrix}k_1\\ k_2\end{pmatrix} = e^{j\Omega}R_{-\Omega}\vec{k}. \qquad (4\text{-}8)$$

(iii)Corrected C2 (covariance matrix) formulation

(iv)Calculation of Polarimetric parameters:

a. Conformity co-efficient:

$$\mu = \frac{2\mathrm{Im}\,\langle S_{\mathrm{RH}}S_{\mathrm{RV}}^{*}\rangle}{\langle S_{\mathrm{RH}}S_{\mathrm{RH}}^{*}\rangle + \langle S_{\mathrm{RV}}S_{\mathrm{RV}}^{*}\rangle} \qquad (4\text{-}9)$$

b. Estimation of bounds for target decomposition:
The conformity co-efficient gives a robust classification parameter represented as follows:

$-1 < \mu < t2$ ~ Double bounce or Ship represented as Red
$t2 < \mu < t1$ ~ Volume or Vegetation represented as Green
$t1 < \mu < +1$ ~ Surface or water/waves represented as Blue

(v) Polarimetric de-composition & comparison.

(vi)Validation with ground truth.

4.7 HISTOGRAM FREQUENCY SLICING CONCEPT:

This is proposed technique of classification of the various clumps after sieving the cutoff or minimum detectable size. This technique has seldom been used as a classification tool and this has been explored and the same has been implemented using original Matlab coding.

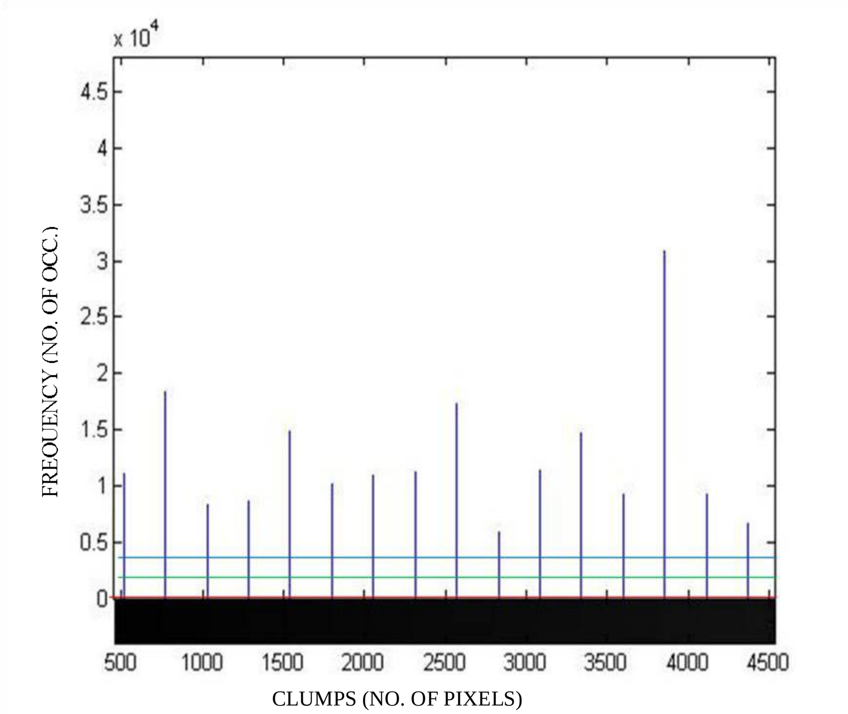

Figure 4.4: Histogram Frequency Slicing Concept

4.8 PROGRAMMING / MODEL OF SHIP DETECTION

4.8.1 SUPPORT VECTOR MACHINE (SVM) IMPLEMENTATION:

After the pre-processing of the image, the detection of ship pixels is handled by the Matlab programs which uses the Statistical and Machine Learning toolbox to implement the Support Vector Machine [5-6] & [9-11] in the following steps:

(i) Database codified as two classes Ship (+1) & Water (-1).

(ii) Two sets of training images for ship pixel and water pixels was selected in a folder/container.

(iii) Read Training Images from the folder/container automatically (two or more for each class).

(iv) SVM train.

(v) Test Image formation for ship detection from the same folder/container automatically.

(vi) SVM Classify.

(vii) Binary Decision Image formation.

4.8.2 ERDAS MODEL IMPLEMENTATION:

The clump and the sieve model is implemented using Erdas Imaging model maker which includes the following steps:

(i) Conditional Thematic conversion

(ii) Clumping (4 & 8 cells)

(iii)Sieving (5 or 10 cells)

4.8.3 ERDAS CLUMP & SIEVE MODEL:

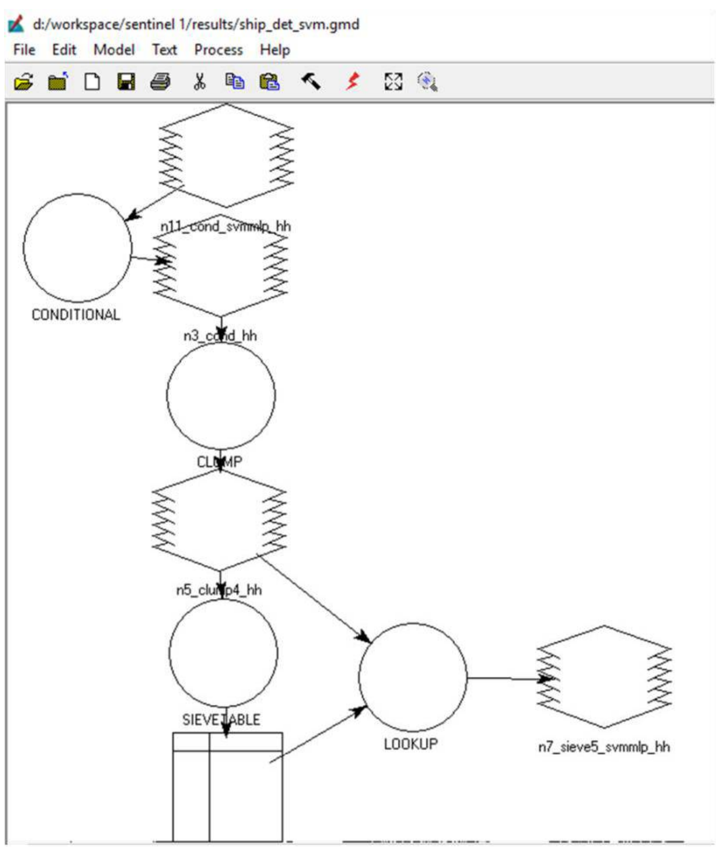

Figure 4.5: Erdas clumb sieve model

4.8.4 HISTOGRAM FREQUENCY SLICING (HFS) MATLAB IMPLEMENTATION:

The sieved image is taken as the input for this module. The major steps included are:

(i) Range definion for classification

(ii) Histogram calculation against each type of scattering

(iii)Image formulation with the class

4.9 SHIP CLASSIFICATION MODEL:

As per International Convention on Tonnage Measurement of Ships, 1969, Regulation 3, the Gross tonnage (GT) is given by

$$GT = K_1 V \qquad (4\text{-}10)$$

where V = Total volume of all enclosed spaces of the ship in cubic metres,

$$K_1 = 0.2 + 0.02 \log10 V \qquad (4\text{-}11)$$

11.4.1 Derivation of Empirical Formula for Volume: The total volume mathematically is defined as

$$V = L \times B \times D \qquad (4\text{-}12)$$

where L is Total Length, B is Total Breadth and D is Total Depth

Then the equivalent estimated total volume can be defined as

Estimated Volume V ~ Range Resolution^2 x Azimuth Resolution x No. of Pixels (4-13)

Also as the depth information is contained in the Range measurement and if Range Resolution = Azimuth Resolution by either sub-sampling or product generation then Empirically, Estimated Volume is derived as

$$V \sim \text{Resolution}^3 \times \text{No. of Pixels} \times f \qquad (4\text{-}14)$$

where f ~ 0.9 (Cargo) depends on the ship design

The value of f was verified for its conformance level by validation with the ship AIS data and port call data on the date of the image. The congruency indicates that the model gives a robust estimation of the gross tonnage and can serve as a source for easy detection without increasing the computational complexity. The factor f is a design parameter which defines the floatation characteristics of the ship and for different types of ships it can be estimated.