CHAPTER 2 RESEARCH METHODOLOGY

2.1 THEORETICAL BACKGROUND:

Detection of ships in the ocean has been done since ages by commercials shipping corporations and military organizations primarily for the major applications that include SAR (Search & Rescue), coastal monitoring, surveillance and maritime reconnaissance. With the development of terrestrial electromagnetic sensors like OTH (over the Horizon) radars for coastal monitoring with limited range and poor detection accuracy, there is a requirement of global coverage which is now being fulfilled by the microwave remote sensing platforms with all weather capability.

Detection is the process of identifying all valid pixels of interest in a given scene in the presence of background noise. Classification is the technique of grouping the pixels of interest with unique attributes that aid in increasing the interpretability of the scene. Technically ship detection problem is a binary decision problem of a given image to find the potential ship pixel (Alternate hypothesis) using a decision variable constrained by a threshold for a stated false alarm else treat as ocean/water (Null hypothesis). Although the problem of ship which is the target being detected seems to be an easier task, it becomes challenging especially in the presence of Clutter which includes manmade, natural or environmental and existing noise due to sensor and processing.

ENVISAT satellite was the first civilian satellite with dual polarization advanced synthetic aperture radar which was launched in March 2002 which formed the genisis of the space-borne polarimetric SAR systems although the airborne polarimetric SAR systems like NASA/JPL's AIRSAR, CCRS/EC's CONVAIR-580 C/X-SAR, DCR's EMISAR & DLR's E-SAR were the pioneers in the polarimetric SAR applications. Most of the initial SAR applications were restricted to the military applications and was not available in public domain or open sources. After the launch of SEASAT, the first ever civilian SAR base Satellite, the open source literature on the ship detection algorithms flourished and further accentuated with the missions like ERS-1 and RADARSAT-1. After the availability of ENVISAT dual pole data, the ship detection algorithms came to literature (Olsen and Wahl, 2003). In Indian scenario, RISAT-1 is the first indigenous multi mode, multi polarization SAR Microwave remote sensing mission which is now operational with the initial results of the data indicating potential applications after the initial calibration and validation (Manab Chakraborty et al., 2013).

The present polarimetric SAR systems have proven that quad-polarised imaging modes and dual polarized image modes give better accuracy than single polarized modes. Some of the studies in ship detection using quad pol include Touzi et al., 2001; Touzi, 2000; Yeremy et al., 2001; Liu et al., 2005 and Liu and Meek, 2005. However, when compared to the swath and the detection accuracy in comparison to system and computational complexity, the performance of the various modes is still not established to be absolute. Considering the problem of ship detection in a vast ocean which requires a wider swath and detection accuracy, dual pole offers better performance over single pole (Liu et al., 2005; Liu and Meek, 2005; Howell et al., 2008) but not better than a quad pol which has the largest back scatter information of the target. Hence the advantages of dual-pol data have increased applications of compact polarimetry or CP data (Souyris et al., 2005; Raney, 2006).

Compact Polarimetry is basically a dual pol SAR based imaging system in which it transmits in one polarization and receives in other two polarizations. There are presently three fundamental CP pol configurations. The $\pi/4$ mode transmits in a linear polarization which is oriented at 45° to the conventional horizontal and vertical polarizations and receives H and V orthogonally. While the Dual circular polarisation is in which it transmits right or left circular polarization and receives both right and left only. Lastly, the circular transmit, linear receive (CTLR) is one which it transmits right or left circular polarization and receives H and V orthogonally (G.E. Atteia and M.J. Collins, 2013). Out of the discussed three modes, the CTLR systems have definite engineering advantages that generate higher quality data (Raney, 2007b; Raney, 2007a). CP SAR systems usage and applications in planetary imaging has been demonstrated by miniSAR on board Chandrayaan-1 (Raney et al., 2010) by the collection of CP based SAR images of our moon (Carter et al, 2011). Presently the only one space-borne CP SAR system is available and that is RISAT-1 launched in Apr 2012 and others in pipeline are Radarsat Constellation Mission and DESDynl (Raney, 2006).

Although there is no CP data available, the various publications have been using CP data that have been simulated from quad-pol data (Souyris et al., 2005; Raney, 2006). Some of the applications of CP SAR data are in the crop classification (Souyris et al., 2005; Ainsworth et al., 2009), vegetation characterization (Angelliaume et al., 2007; Lardeux et al., 2011), Soil moisture estimation (Truong-Loi et al., 2009) and land cover mapping (Ainsworth et al., 2009; Nor et al., 2009). Specific to the field of target identification, the use of CP data to detect icebergs (Denbina and Collins, 2012) and for ship detection (Yin et al., 2011; Shirvany et al., 2012 G.E. Atteia and M.J. Collins, 2013) has been carried out.

2.2 POLSAR PROCESSING:

2.2.1 RISAT-1 DATA PROCESSING:

2.2.1.1 Calibration of the data:

Calibration is the procedure of quantitatively defining the system responses to known, controlled signal inputs. With calibration of SAR data radiometrically, it is feasible to evaluate values obtained by one SAR sensor to that obtained by other SAR sensors and also to ground based observations. Thus, one is able to extend results of remote sensing studies carried out using one sensor. This has lead to the growth of robust models for retrieval of parameters for various remote sensing applications. For SAR images the Digital Number (DN) is a number whose value is directly proportional to the received voltage by the SAR antenna. Therefore the image intensity is proportional to the received power. This process of retrieving the backscatter coefficient from the received SAR image intensity is known as the radiometric calibration. This typical calibration has been performed over the given dataset according to the relation given below:

$$\sigma = (DN)p \times \sqrt{\frac{\sin(ip)}{\sin(ic)}} \times \frac{1}{\sqrt{10(k/10)}} \qquad (2\text{-}1)$$

(*Kumar, Gupta, Gonnuru, & Joshi, 2016*)

2.2.1.2 Scattering Matrix Generation:

Radar wave when interacts with a surface, it changes its polarization state. Therefore the backscatter received at the sensor will have orientation in two polarization i.e., horizontal and vertical both. These received backscatter is stored in the form 2 x 2 scattering matrix which is given as

$$[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \qquad (2\text{-}2)$$

Here, each element denotes the backscatter information of the target in all the four polarizations. The extracted data contains the information regarding the amplitude and phase of the response of the scatterer in the form of complex value.

2.2.1.3 Coherency matrix generation:

Complex information about different scatterers present within a single SAR resolution cell is extracted from coherency matrix extracted from multi-looked complex SAR data. This matrix is obtained from the Hermitian product of the Pauli basis and describes the local variations in the scattering. The vectorised form of the scattering matrix in Pauli basis is given as

$$k_p = \frac{1}{\sqrt{2}} \begin{bmatrix} S_{HH} + S_{VV} \\ S_{HH} - S_{VV} \\ 2S_{HV} \end{bmatrix} \qquad (2\text{-}3)$$

The coherency matrix so obtained is given by

$$\langle [T] \rangle = \langle k_p k_p^{\dagger} \rangle \qquad (2\text{-}4)$$

where $\dagger$represents complex conjugate and transpose, $\langle\ \rangle$ $\langle \ldots \rangle$represents the spatial average over the whole data. The coherency matrix obtained using (2-3) is given as

$$\langle [\mathrm{T}] \rangle = \begin{bmatrix} \langle |S_{HH} + S_{VV}|^2 \rangle & \langle (S_{HH} + S_{VV})(S_{HH} - S_{VV})^* \rangle & 2\langle (S_{HH} + S_{VV}) S_{HV}{}^* \rangle \\ \langle (S_{HH} - S_{VV})(S_{HH} + S_{VV})^* \rangle & \langle |S_{HH} - S_{VV}|^2 \rangle & \langle (S_{HH} - S_{VV}) S_{HV}{}^* \rangle \\ 2\langle S_{HV}(S_{HH} + S_{VV})^* \rangle & 2\langle S_{HV}(S_{HH} - S_{VV})^* \rangle & 4\langle |S_{HV}|^2 \rangle \end{bmatrix} \qquad (2\text{-}5)$$

Elements T_{11},T_{22} and T_{33} are sensitive to surface, double bounce and volume scattering from a single SAR resolution cell. The sum of the diagonal elements represents the total backscattered power of wave. Also the Eigen values of both the covariance matrix and coherency matrix are same.

2.2.1.4 Pseudo Hybrid C2 matrix Generation:

The Fully polarimetric Quad data is converted to the right circular polarized dual band data. The data is in the form of RH and RV and the same process can be used to convert Psuedo Quad data from a received RH and RV components of CFRS mode.

2.2.1.5 Compact polarimetric decomposition:

m-δ decomposition : Raney (2007) proposed a decomposition theorem based on stoke's parameters. From the stoke's parameters, he calculated various polarimetric parameters for the decomposition. The stoke's parameters for hybrid polarimetric SAR (RISAT-1) are defined as follows:

This method is based on the degree of polarization and polarization angle. It is expressed through:-

Blue ~ Surface scattering = [m*S_0 (1-sin (pi/2- 2α))/2]1/2
Red ~ Double bounce scattering = [m*S_0 (1+ sin (pi/2 - 2α))/2]1/2
Green ~ Volume scattering = [S_0 (1-m)] 1⁄2

Where m is degree of polarization, S_i represents stokes vectors (i=0, 1, 2 & 3) and α is polarization angle;

$$\alpha = \text{angle};\ \alpha = 0.5 tan^{-1} \frac{\sqrt{S1^2 + S2^2}}{S3} \qquad (2\text{-}6)$$

Degree of polarization (m):

It defines the quantified amount of wave polarized to that of it that is unpolarized. Further it is the ratio of the power of polarized wave to the total power of the electromagnetic (EM) wave. Its value exists between 0 and 1; which indicates the polarized and diffused scattering mechanisms. If m is equal to 1, it is deduced that the wave is fully polarized and is equal to zero for a partially polarized wave

$$m = \frac{\sqrt{{s_1}^2 + {s_2}^2 + {s_3}^2}}{s_0} \qquad (2\text{-}7)$$

The degree of polarization varies 0 to 1. For Fully polarimetric data the value of the Degree of polarization should be 1.

2.2.1.6 Geo-coding:

Geo-coding is performed in order to establish a relationship between the SAR image with the real world. The given SAR geometry is transformed from range azimuth coordinates to UTM based co-ordinate system with WGS-84 datum.

2.3 SOURCES OF DATA:

The Primary data source is the CP data from NDC (NRSC Data Centre), NRSC (National Remote Sensing Centre), ISRO (Indian Space Research Organisation) of the RISAT-1 and Sentinel 1A data from Sentinels Scientific Data Hub - https://scihub.copernicus.eu of Mumbai area. The secondary data sources include port calls and Archival AIS (Automatic Information System) data of the Mumbai port area and Ship Identification & Meteorological data from Sea-web (a unit of IHS previously Lloyds database), VT Explorer (Astra Paging Limited), www.marinetraffic.com and/or from the Director General, Shipping Corporation, Mumbai for ground truth and validation.

2.4 SAMPLING OF DATA:

Considering the volume of the data, the data is filtered by masking the land portion and only the sea portion is being analysed for swath of about 25 KM over the available image for further analysis and integration of the data. The data is processed at the resolution provided by the source with required filtering techniques as per the type of data to maintain data integrity. Intentionally the masking of land has been kept in the later part of algorithm so as to assess the capability of the algorithm to delineate any land feature of interest. Keeping the target of interest as ships of cargo type with Gross tonnage of 1000 ton, there is requirement of a minimum resolution of 33m. Hence the medium resolution products of mean resolution of 10m of Sentinel

1A IW mode for cross validation and products of mean resolution of 18m for RISAT-1 MRS mode and mean resolution of 3m for RISAT-1 CFRS mode is used.

2.5 STATISTICAL AND ANALYSIS TOOLS:

The analysis tools and the statistical tools included in the toolbox that are used in the research are:

(i) PolSARPro version 5 or higher version (ESA SAR Toolbox)

(ii) Erdas Imagine 2014 package and toolbox

(iii) Exelis Envi 5.0 with SarScape 5.0 toolbox

(iv) Sentinel1A toolbox & SNAP desktop version

(v) SARCview tool of SAC (Space Application Centre)

(vi) Kappa statistics of classification accuracy and validation.