Automatic Ship Detection using Dual Polarimetry SAR Satellite Imagery

Synopsis submitted in partial fulfillment of the requirement for the Master of Technology in Remote Sensing and Geographical Information System with specialization in Satellite Image Analysis and Photogrammetry.

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1. Introduction

1.1 Synthetic Aperture Radar

Synthetic Aperture Radar (SAR) imagery is a prominent data source for the surveillance of maritime activity. Automatic ship detection using SAR imagery has evolved as the major research subject in recent times. SAR plays a vital role in detecting the objects by using its capability of backscatter image. The intensity of each pixel basically represents the proportion of microwave back-scattered energy from that area on the ground which is crucially dependent upon various factors like type, size, shape, orientation of the scatterers in that target area. The energy back-scattered by metallic objects is quite high due to its dielectric properties and thus metallic objects appears as bright pixels in the SAR imagery. However, energy back-scattered by the water body and sea is quite low due to specular reflection and thus water bodies appeared as dark pixels in the SAR imagery. Thus, Ship detection is found to be better in the SAR imagery as compared to the optical imagery. The geometry of the SAR data acquisition is shown in figure 1 below.

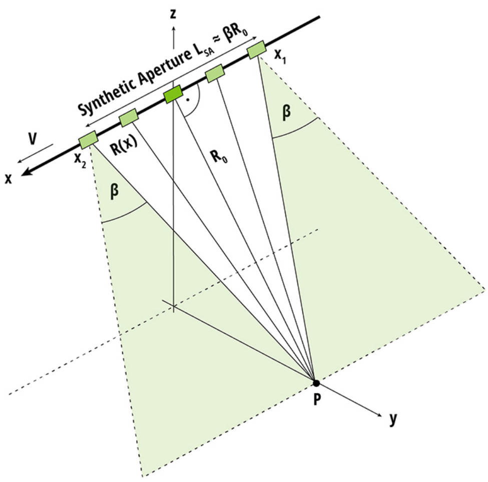

Figure 1: Geometry of Synthetic Aperture Radar Data Acquisition

1.2 Interpretation of SAR Images

Interpreting SAR images involves the principles of wave interaction with the target surface and scattering principles. Scattering mechanism can help us in interpreting the SAR images, for example in case of soil, scattering principles helps in understanding wave-soil interactions with different type of soils. In case of dry soil, the incident radar signal energy is able to penetrate into the soil. In case of wet soil, the dielectric property of water affects the penetration power of radar energy. In the similar way, flooded soil can be detected as the specular reflection of the radar energy. In maritime application, backscatter energy of the ships is quite high thus they appeared as bright objects while sea appeared as dark background. However, backscatter energy also depends on the incident angle, thus detection of ship depends on the incident angle of the SAR beam. Detection of the ship in the sea also depends on the sea state and also influenced by SAR ambiguities. The figure 2 below shows the ship as the bright targets in the SAR image.

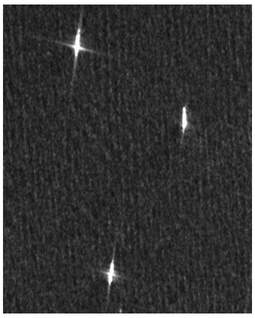

Figure 2: Ships in the SAR Image

1.3 Dual Polarimetry SAR data

Polarimetry is the science of measuring orientation and object shape through the geometrical properties of EM propagating in space. In particular, the shape that the electric field draws with time on the plane transverse to the direction of propagation contains the information on the interaction between the EM with the material bodies and with the propagation medium. For example, two different targets interact with the same polarized EM scattering a wave with different polarimetric signature. Therefore, this can be exploited to discriminate among observed targets. Signals with components in two orthogonal or basis polarizations are needed to create a wave with an arbitrary polarization. The two most common basis polarizations are horizontal linear or H, and vertical linear or V. In figure 3, H and V polarization of the transmitted Electromagnetic wave are shown.

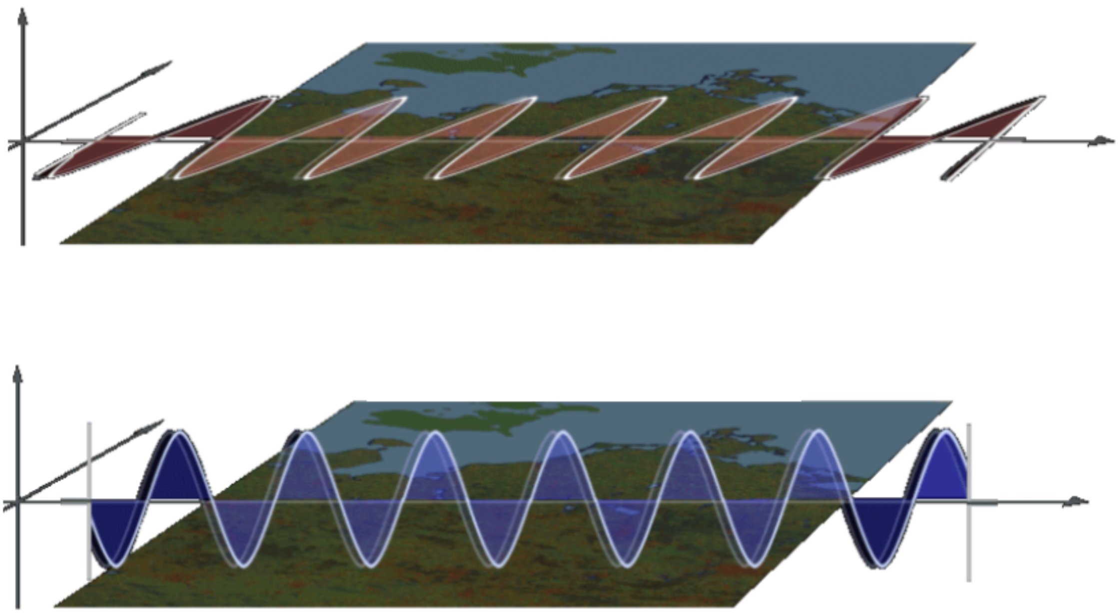

Figure 3: Horizontal polarization (H) and Vertical Polarization (V)

In Horizontal polarization, Electromagnetic waves enhances the backscatter information of the horizontal surfaces. While in Vertical polarization, Electromagnetic enhances the backscatter information of the vertical features. In SAR systems, the antenna may be designed to transmit and receive waves at more than one polarization. On transmit, waves of different polarizations can be transmitted separately, using a switch to direct energy to the different parts of the antenna in sequence. Because the scatterer can change the polarization of the scattered wave to be different from the polarization of the incident wave, the radar antenna is often designed to receive the different polarization components of the EM wave. In Dual polarimetry SAR systems,SAR transmits in one polarization and receive in more than one polarization. Thus, Dual Polarimetric system can be VV+VH or HH+HV. In VV+VH mode , SAR transmits V polarization and receive in V and H polarization. In HH+HV mode , SAR transmits H polarization and receive in H and V polarization. Sentinel-1 mission has the dual polarimetry mode operation in VV+VH or HH+HV.

1.4 **SAR Imaging and Ship Detectability**

Basically ships are formed from large flat metal sheets and hence they are usually seen by radar as bright objects. Radars can efficiency detect the ships using backscatter (Kang et al., 2017) imagery from the ship but SAR ambiguities and sea clutter can falsely detect as ships. CFAR is the most standard techniques to detect the ships. The details of this techniques is discussed in the literature review section This technique need to be stated with different polarization channels which makes it more compact to deal with the radar techniques. Many improved CFAR algorithms are developed and among those, one of the ship detection algorithm is Bilateral based CFAR algorithm which shows the better results as compare to standard CFAR algorithm. But most of the algorithm worked on the single polarization data. Dual polarimetry datasets enhance the ship detection by fusing the information from both channels of polarization i.e. VV+VH or HH+HV. Sentinel-1/1B satellites provide dual polarimetry data sets with 10 m resolution with global coverage and having good revisit time. Land Water segmentation would be one of the major tasks for the sea-coastal areas for segmenting the water and land mask so that ships can be easily detected.

1.5 **Sentinel-1A/1B SAR Satellites**

Sentinel-1A/1B SAR satellites are specifically designed to acquire systematically and provide routinely data and information products for Ocean, Land and Emergency services. These cover operational applications such as the observation of the marine environment, including oil spill detection and sea-ice monitoring, the surveillance of maritime transport zones (i.e., ship detection), as well as the mapping of land surfaces including vegetation cover (e.g. forest) and mapping in support of natural disaster and crisis situations. It has 12-day repeat orbit cycle of each satellite. It will provide data in either VV+VH or HH+HV but most of the available datasets in VV+VH mode as its default mode of operation. So, frequent Sentinel-1A/1B datasets are available with 6 days interval and hence, a robust algorithm is needed to develop for ship detection for dual Polarimetry data which will detect ships accurately in an operational scenario. The figure 4 below shows the different modes of Sentinel-1A/1B mission.

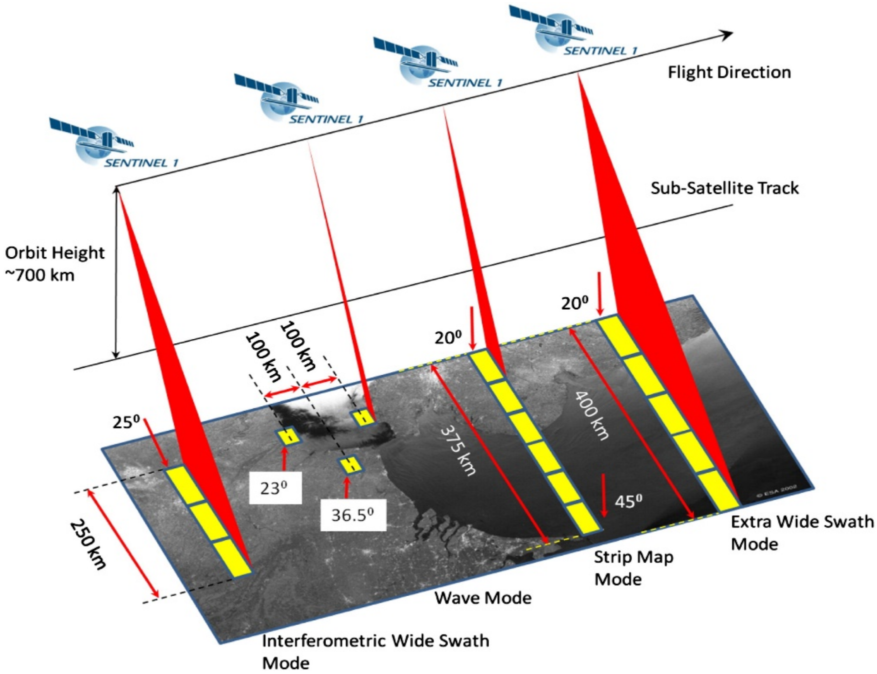

Figure 4: Sentinel-1 SAR Mission

2. Literature Review

2.1. Constant False Alarm Rate (CFAR)

In ship detection, Constant False Alarm Rate (CFAR) algorithm is widely used for detecting ships in the sea coast area . According to (Kang et al., 2017), it offers the low-loss constant false alarm rate performance in uniform environment as well as it is highly robust in nature for some in-homogeneity such as multiple target and clutter edges. In the figure 5, the CFAR algorithm methodology has been shown.

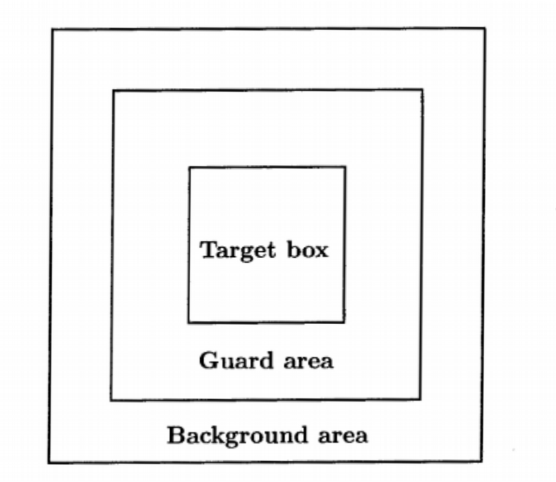

Figure 5: Basic Convention of CFAR Algorithm

A CFAR algorithm is used to detect the multiple targets with the threshold determined by the pixel's amplitude (Quina et al., 2019) in the target and background window. Adaptive threshold basically helps to search for pixel value which are usually bright as compared with the surrounded area. This is done by using threshold T which do depend upon the statistics of the neighboring area and the probability density functions which is given by equation 2.1.

$$PFA = 1 - \int_{-\infty}^{T} f_{pdf}(x)\,dx = \int_{T}^{\infty} f_{pdf}(x)\,dx \quad \text{eq. (2.1)}$$

Here, the target area is composed of pixel under test that which is surrounded by a guard area which ensures that no pixels of the target area are included in the background area. Hence, background statistics is the representatives of detecting the threshold. In the context, all the windows are moved one pixel at a time across the whole image. The basic aim of this design is to ensure that the probability of a false alarm is constant. In the studies (Dalmiya et al., 2019), the threshold is chosen so that the percentage of background pixel values which lies greater than the threshold is constant.

In CFAR algorithm, threshold is estimated by computing the level of noise around the cell under test (CUT). This can be done by computing the average power cell. This helps in detecting the noise within the desirable limits and leads to detect the object of interest

Designing a CFAR detector based on the Gaussian model leads to the two parameter CFAR detector. In this case, the detector is

$$x_t > \mu_b + \sigma_b t \qquad \text{eq. (2.2)}$$

Where x_t is the pixel value under test, μ_b is the background mean, σ_b is the background standard deviation, and t is a detector design parameter which controls the PFA (or equivalently the false alarm rate). In practice, t is fixed, μ_b and σ_b are estimated from the samples in the background.

2.2. Bilateral Filtering

In the conventional CFAR algorithm, the Gaussian filters are most commonly used for the kernel functions. Those filters strictly follows the spatial distances in the window kernel. But in Bilateral filtering, it is the combination of intensity distribution and spatial distribution both. According to the relationship between intensity distribution and spatial distribution (Paris et al., 2013). This method helps in coordination in both domain spatial as well as intensity. In the figure 7 shown is the example that how bilateral filter smooths an input image while preserving its edges. Each pixel is replaced by the weighted average of its neighbours. Each neighbour is weighted by a spatial component that penalizes the distant pixels and range component that penalizes pixel with the different intensity. The combination of both the components that are spatial and intensity ensures that only nearby similar pixels contribute to the final results.

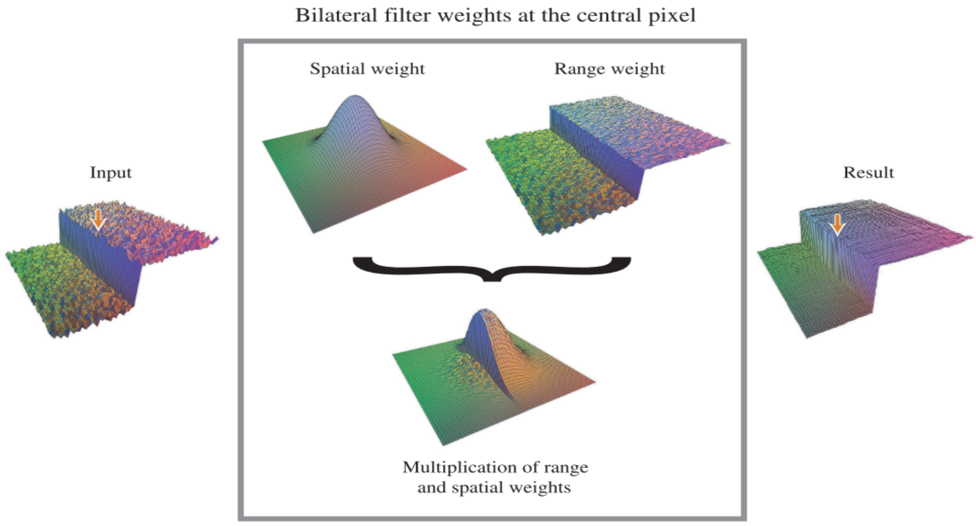

Figure 6: Bilateral Filter: An Overview

2.2.1 Bilateral CFAR

The conventional CFAR detection is designed to search for pixels which are usually bright compared to background, and SAR ambiguities or sea clutter may meet this condition too. Thus, it is not enough for CFAR detection that statistical model only take into account intensity distribution. Ship targets in the SAR image differs not only in the intensity domain but also in spatial domain. Bright pixels of the ship targets are continuous while bright pixels in background are random and unstable. Thus, spatial information also crucial for detecting ship from sea clutter or ambiguities. In order to apply CFAR using Bilateral concept, combined construction of spatial and intensities distribution is needed. There are two approaches (Leng et al., 2015). In first one, we implement standard CFAR detections to both intensity and spatial distribution separately. Then combining the result through some operations. Another approach is to combine intensity and spatial distribution first and then process CFAR detection is implemented over the combined distribution. Thus, it can be said that the value $x_{combined}$ can be defined as-

$$x_{combined} = x_{(intensity_j)} * x_{(spatial_j)} \qquad \text{eq. (2.3)}$$

Hence, the average value for each pixel is further evaluated by

$$x_{combined} = \frac{4}{(w \times w)} \sum x_{(combined_j)} \qquad \text{eq. (2.4)}$$

Where, $\Omega(w)$ is the fixed-sized sliding window and w is the width of the window. Basically w is determined by the size of ship targets and sea clutter. After calculating the combined distribution, standard CFAR detection is implemented.

2.3. Land-Water Segmentation

Ship detection systems includes the major part of Land water segmentation, in which we generally mask the land coastal area in order to draw water bodies to implement on ship detection. In raster images, we can segment the coastal area using like edge detection and image segmentation methods. For geocoded SAR products having information of latitude and longitude, land water segmentation can be done using coast line vector data. In this, either Global 250m MODIS Water Mask Library or GSHHS (Global Self-consistent, Hierarchical, High-resolution Shoreline) can be used for land -water segmentation (Kovesi, 2003).In this study, geocoded products will be taken as input and image based or vector layer based approaches will be attempted for land water segmentation based on geolocation accuracy of the geocoded SAR products.

3. Problem Statement

Ship detection using SAR imagery is the crucial application for monitoring many maritime activities. Although, SAR imagery is better than optical satellites for ship detection but sometimes SAR ambiguities also falsely detected as ships. State of the sea also influence the ship detection process. Dual Polarimetry data contains the information from both polarimetric channels so the information can be fused to increase the ship detection capability in presence of SAR ambiguities.

Most of the ship detection algorithm uses intensity distribution in the SAR images to detect ships and spatial distribution is not used. Bilateral filter is the common filter which uses the intensity distribution and spatial distribution to remove falsely detected ships or targets in the images. Bilateral based CFAR algorithm can be used for better detection of the ships.

In coastal Areas, application of the ship detection algorithm can lead to detect target in the land areas. Thus, land areas should be masked out before applying the ship detection algorithm. Land-water segmentation is the primary step for the implementation of the ship detection algorithm. Land-water segmentation could be done using image based methods or using vector coastline database. In vector-based approaches, geolocation accuracy of the geocoded SAR products plays important role in masking land and water areas. Therefore, it a challenge to detect water surface precisely to detect ships and other object of interest.

4. Motivation

Synthetic Aperture Radar is well known in remote sensing application for providing 24 hour all-weather sensing capabilities. It majorly helps in detecting features, understanding the textures by its remarkable polarization techniques. Sentinel-1A/1B is one of the most useful Satellite mission that helps in various SAR applications in global monitoring from space on ocean environment and maritime traffic. It has 12-day repeat orbit cycle of each satellite. It will provide data in either VV+VH or HH+HV in a frequent time interval of 6 days. Thus, Sentinel-1A/1B SAR dual Polarimetry datasets are the vital source of the dual polarimetric SAR datasets for ship detection.

5. Innovation

In the previous studies, the most of the ship detection algorithm has been implemented over single polarized data. In the proposed study, new methodology would be developed for fusing the information from both polarization channel i.e. VV+VH or HH+HV for the detection of the ship using bilateral based CFAR algorithm.

6. Research Objective

In the study, the main objective is to develop the methodology for ship detection using dual Polarimetry SAR data and advance bilateral based CFAR kernel.

6.1. Research Sub-Objectives

- To develop the bilateral based CFAR kernel.
- To develop the methodology for single polarimetric SAR data for ship detection using bilateral based CFAR kernel
- To develop the methodology for dual polarimetric SAR data for ship detection using bilateral based CFAR kernel.
- Analysis of results and error bars through ROC curves.

6.2. Research Questions

- How to fuse the information from VV and VH polarization using bilateral based CFAR to detect ships?
- What optimum parameters to be used in Bilateral based CFAR to combine intensity and spatial distribution?
- The performance of the proposed methodology to detect ships in presence of ambiguities or sea clutter?
- The performance of the proposed methodology to detect ships in coastal as well as deep sea area?

7. Datasets and Study Area

Sentinel-1A/1B mission Ground Range Detected Full resolution product will be used with the VV+VH or HH+HV polarization in this study. The resolution of Sentinel-1A/1B SAR imagery is 10 m. The proposed algorithm would be developed to work on any dataset containing ship in coastal area or deep sea. However, for developing and testing the algorithm, the area chosen for the study is Mumbai, India west coastal area (Lat, Long 18^{0} $57^{'}$ 34 N, 72^{0} $50^{'}$ 38 E) . The Jawaharlal Nehru port trust (JNPT), also known as Nhava Sheva port, is the busiest port in India. In the figure 8 , the bright pixels in the ocean represents the ships.

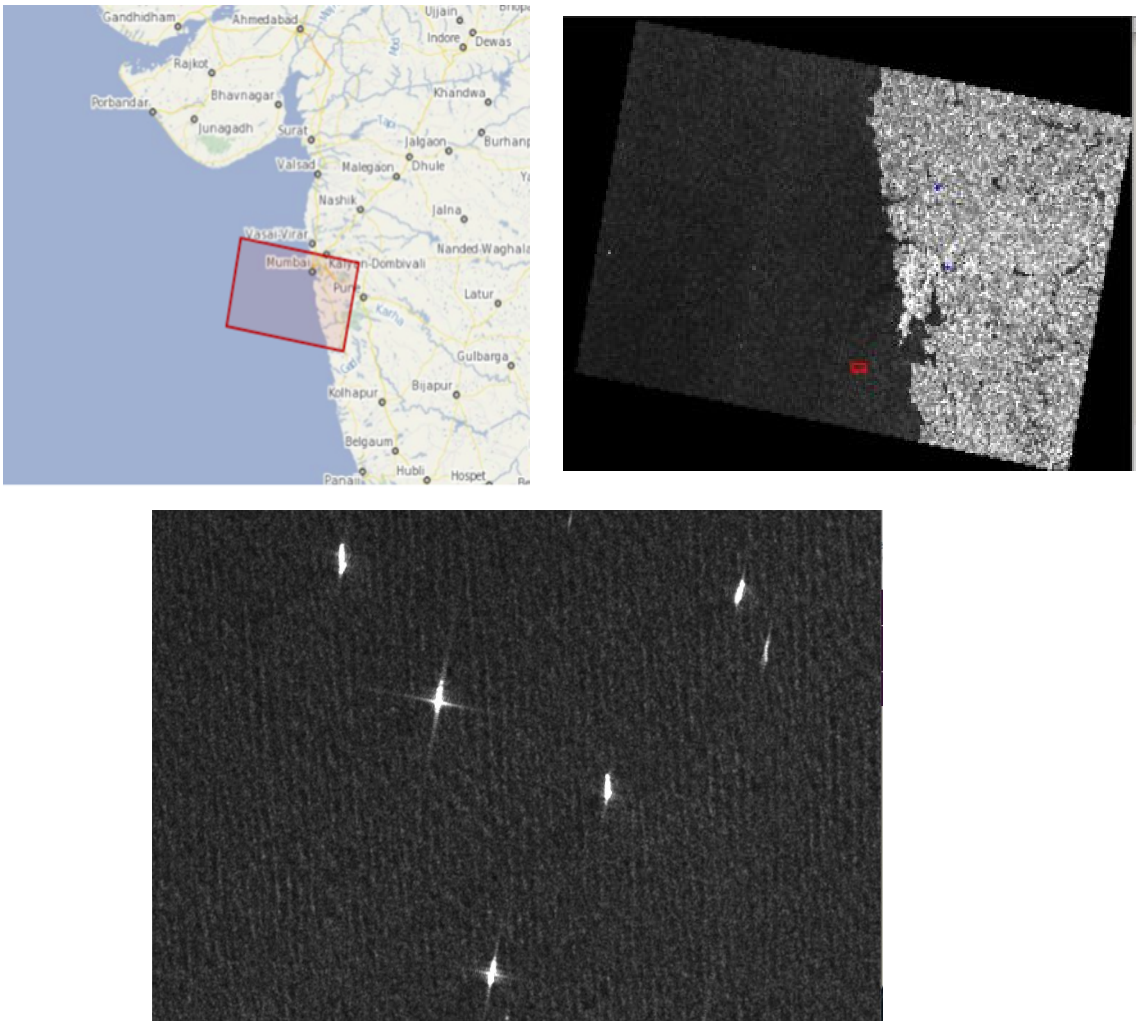

Figure 7: Sentinel-1A Image (VV Polarization: Mumbai)

8. System Requirements

8.1. Hardware Requirements

- Processor: Minimum 2.3 GHz Processor
- Memory: Minimum 8GB RAM

8.2. Software Requirements

- Jupyter Notebook
- Python 3.6
- MATLAB
- SNAP
- QGIS

9. Methodology

The methodology flow of work for the study is described in the figure 8. The basic steps for the proposed methodology are:

- Sentinel 1A/1B ground range products of VV and VH polarization are converted to Ellipsoid corrected/Terrain corrected geocoded products using SNAP software.
- Land-water masking for the retrieval of water surface would be done on Geocoded VV and VH products. This land water masking would be performed using image based or coastline vector layer-based methods.
- After masking the land surface ,water surface containing the ships can be generated, from this we can estimate different statistical parameters for Bilateral CFAR algorithm.
- Then, Dual polarimetry based bilateral CFAR algorithm would be applied to fuse the information from both VV and VH datasets.
- Lastly, Analysis of the performance would be evaluated using ROC curves for validation of the methodology.

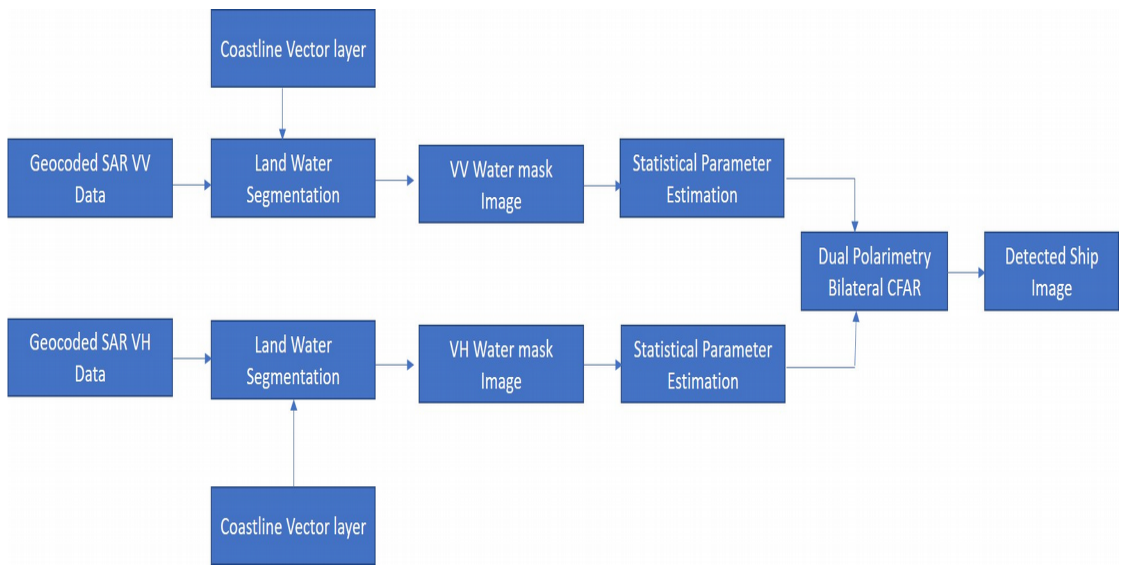

Figure 8: Flow chart of the Proposed Methodology

10. Expected Results

- Binary Image of the detected ships.
- Land masked image.
- Analysis of the results and outputs through ROC curves.

11. Timeline

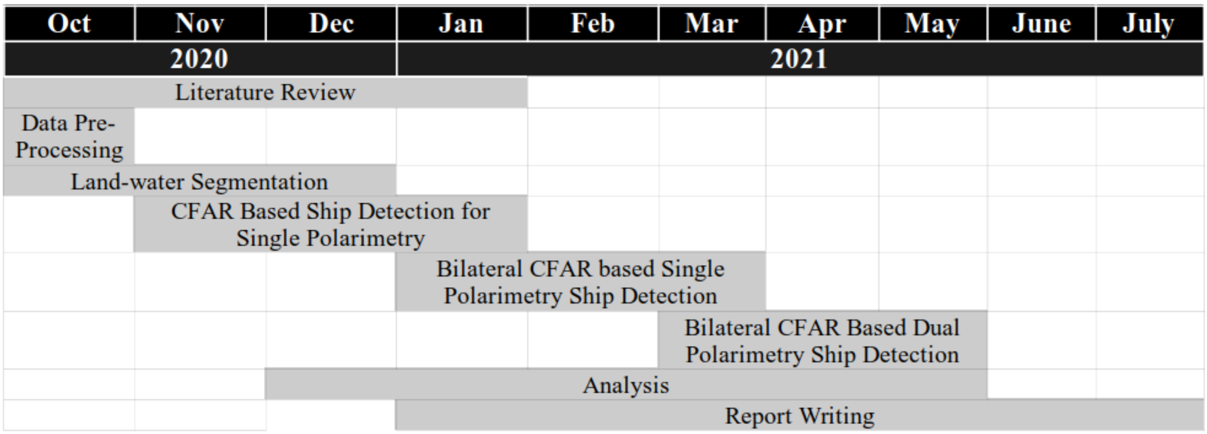

Figure 9: Timeline of the proposed work.

The timeline of the project is shown in the figure 9.

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