ESTIMATION OF SHIP VELOCITY BY USING SAR IMAGERY - SIMULATION METHODS

ABSTRACT

The estimation of ship heading and speed from a high resolution ***Synthetic Aperture Radar (SAR)*** *image of ship and its wake is important for monitoring and tracking ships. In order to get a correct and focused image of the moving ships, it is necessary to know the real positions and velocities of the ships. Though the ship can often be imaged clearly, its orientation may be difficult to estimate from its image because of the effects of ship motion. The wake can provide direct information about the ship heading. The cross range separation between the location of the ship in the image and the wake can also provide an estimate of the ship's velocity. We propose a strategy based on the generalized Radon Transform and the Stochastic Matched Filtering where the locus of the wake signature in the 2D spectrum of the image is to be detected.*

In this work we propose three simulation methods for estimation of ship velocities, and directions using SAR imagery. The knowledge of these parameters is used to compensate the SAR image, i.e. to eliminate the imaging errors due to object motion. The proposed methods are based on evaluation of a sequence of single–look SAR images, generated from conventional SAR raw data.

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INTRODUCTION

1.0 Synthetic Aperture Concept

Synthetic-aperture radar (SAR) is a form of radar in which the large, highly-directional rotating antenna used by conventional radar is replaced with many low-directivity small stationary antennas scattered over some area near or around the target area. SAR can only be implemented by moving one or more antennas over relatively immobile targets, by placing multiple stationary antennas over a relatively large area, or combinations thereof. SAR has seen wide applications in remote sensing and mapping.

Synthetic Aperture is when a narrow pulse in range is created (or synthesized). To create such pulse, signal is frequency-modulated. Therefore, the signal frequency changes in time. Effectively, the series of observations can be combined just as if they had all been made simultaneously from a very large antenna; this process creates a ***synthetic aperture*** much larger than the length of the antenna (and much longer than the aircraft itself).

Combining the series of observations requires significant computational resources. It is often done at a ground station after the observation is complete, using Fourier transform techniques. The high computing speed now available allows SAR processing to be done in real time onboard SAR aircraft. The result is a map of radar reflectivity (including both amplitude and phase). The phase information is, in the simplest applications, discarded. The amplitude information contains information about ground cover, in much the same way that a black-and-white picture does. Interpretation is not simple, but a large body of experimental results has been accumulated by flying test flights over known terrain.

A scale hologram interference pattern was produced directly from the analogue radar data (for example 1:1,000,000 for 0.6 meters radar). Then laser light with the same scale (in the example 0.6 micrometers) passing through the hologram would produce a terrain projection. This works because SAR is fundamentally very similar to holography with microwaves instead of light.

1.1. SAR Geometry

Figure-1.1 shows a simple model of a SAR system regarding radar location and the beam footprint on the Earth's surface. The radar system can be mono-static, bi-static or multistatic, depending on the location of the receiver. In a mono-static system, same radar antenna is used to receive signals. This is the type of system typically used for remote sensing.

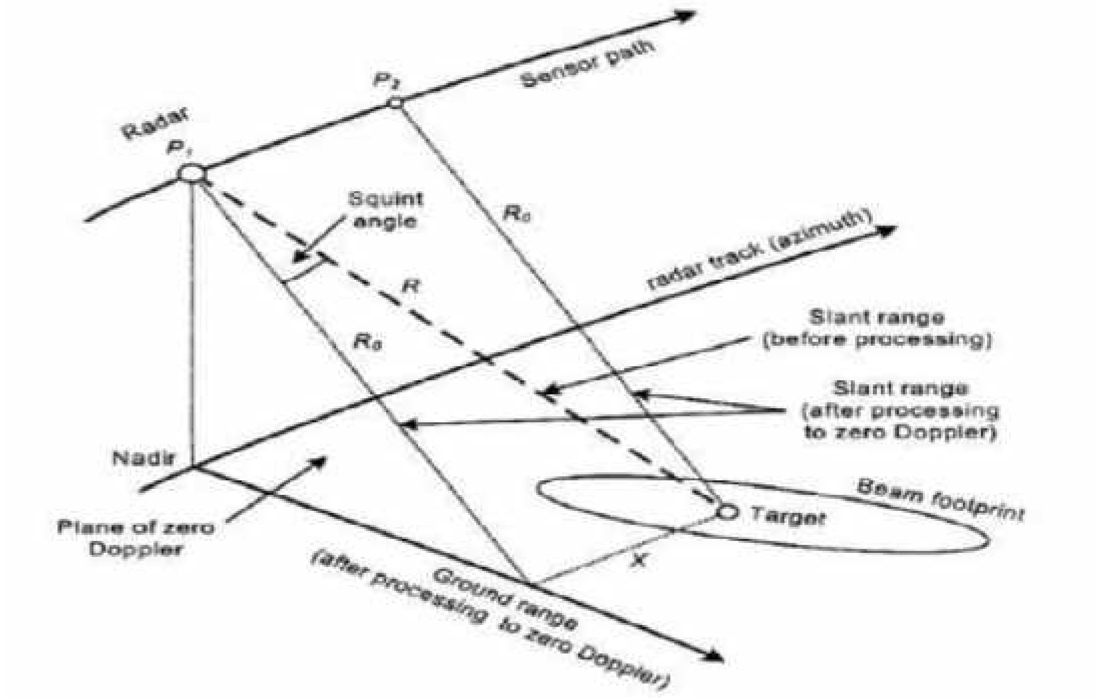

Figure-1: SAR Geometry

The SAR image formation produces an image in slant range and azimuth coordinates. It is often desirable to resample the image to coordinates corresponding to those of a map or an optical sensor, where the range and azimuth axes have equal scales.

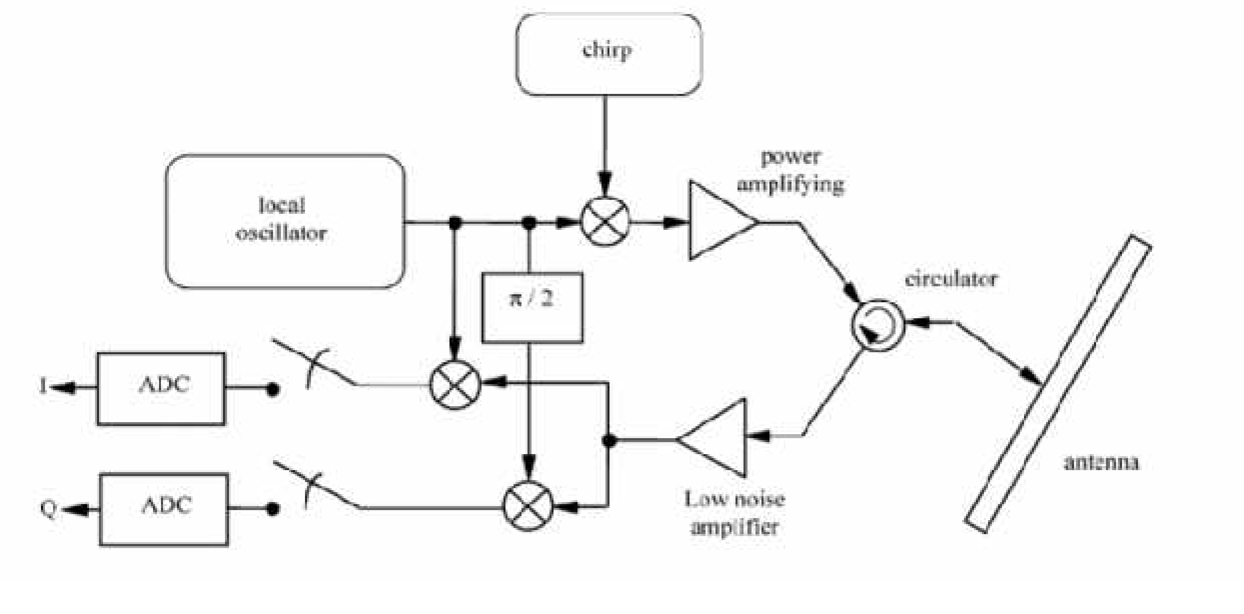

Figure-2: Typical Block diagram of radar instrument

1.2. General Structure of SAR System

Main parts of a SAR system are depicted in Figure-. A pulse generation unit creates pulses with a bandwidth according to the aspired range resolution. They will be amplified by the sender and are transferred to the antenna via a circulator. The receiver gets the antenna output signal (echoes of the scene) amplifies them to an appropriate level and applies a band pass filter. After the demodulation and A/D conversion of the signals the SAR processor starts to calculate the SAR image. Additional motion information will be provided by a motion measurement system. A radar control unit arranges the operation sequence, particularly the time schedule.

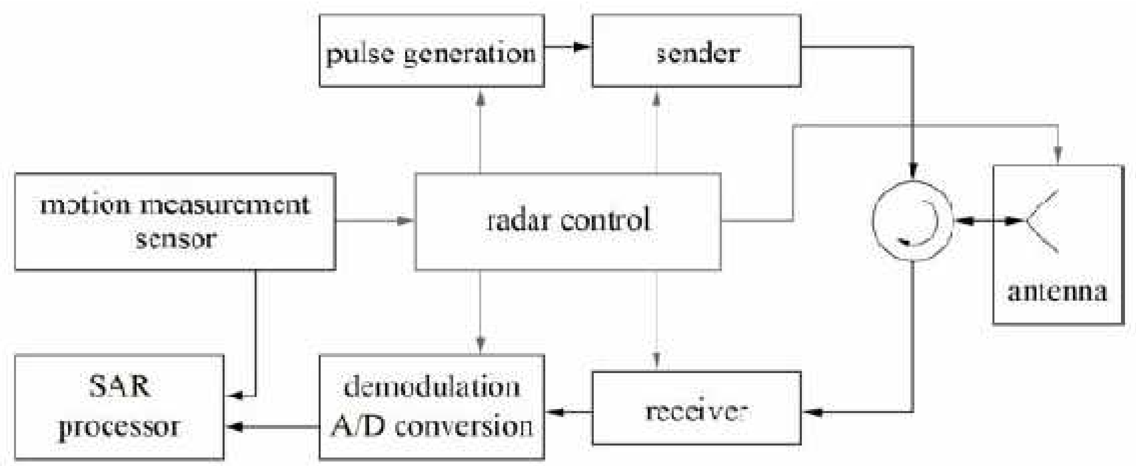

Figure-3: General structure of a SAR system

1.3 Applications of SAR

SAR has got a broad range of applications. For remote sensing a couple of earth observing satellites are currently in operation, having imaging sensors working in different spectral areas. The utilisability of optical sensors depends not only on daylight but also on the actual weather conditions. Clouds and strong rain are impenetrable for this wavelength. Infrared sensors which are applicable day and night are even more sensitive on weather conditions. Consequently, radar sensors represent a completion of the sensor collection for remote sensing. Beyond the overall availability of SAR images there are further pros for the utilization of radar. The coherent nature of SAR enables the user to process images of subsequent over flights for interferometrical analyses. Depending on the radar wavelength the radar signal will be reflected by vegetation or the ground structure. With the choice of a concrete centre frequency of the SAR sensor, the developer decides about the appearance of the resulting radar images. Different combinations of the transmit and receive polarization can also be used for instance to classify the kind of vegetation.

The exploitation of the relative motion between the sensor and the scene is an essential drawback of the SAR principle. While this motion can be derived completely for a fixed scene from the motion data of the SAR platform, moving objects own an additional motion component which disturbs the imaging process.

Operation of a bi- or multi-static configuration offers some more advantages. The receiver system, including expensive acquisition electronics, need not to transmit any energy and thus can be designed hardly detectable. Stealth targets feature a minimized mono-static radar cross section (RCS). Target echoes might be considerably higher in a bi-static configuration so the probability of detection will be increased.

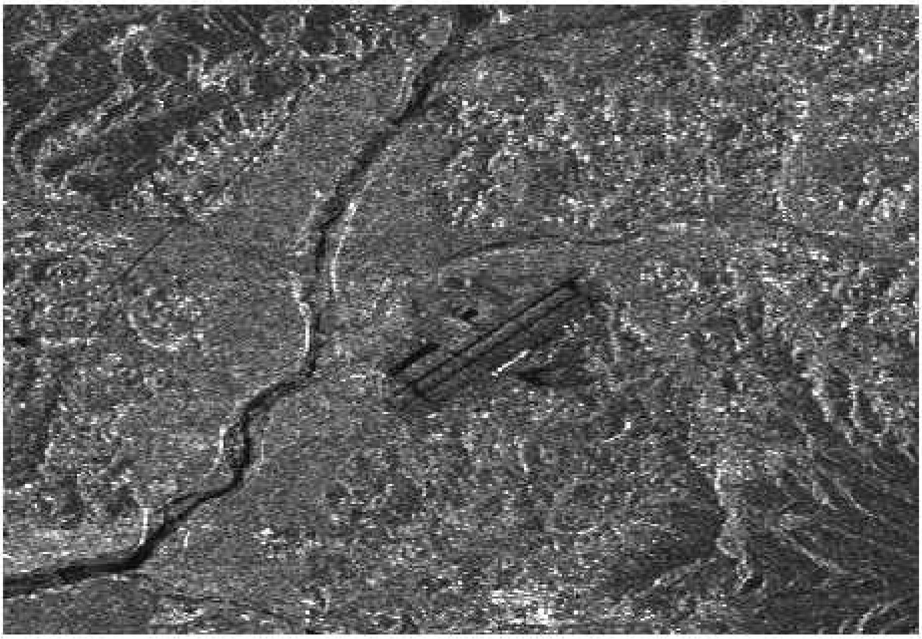

Figure-4: Example of extracted SAR raw data

1.4 Methodology

In this project we propose three methods to estimate the ship velocity using SAR imagery.

1. Cross Range Separation Technique.
2. SOVE Algorithm Technique.
3. Stochastic Matched Filtering Technique.

1.5 Cross Range Separation Technique:

Basic Principle:

The Synthetic Aperture Radar (SAR) is able to achieve high azimuth resolution by storing and reconstructing all the returned signals in the 'synthesized aperture'. By moving the radar antenna while illuminating the target and coherently processing the returned signals, a large radar aperture is synthesized thus achieves high azimuth resolution. In processing the returned signal, SAR processors assume targets to be stationary.

Detection Algorithm:

The basic structure of the detection algorithm is summarized in figure 3.5. Each step of the detection is introduced.

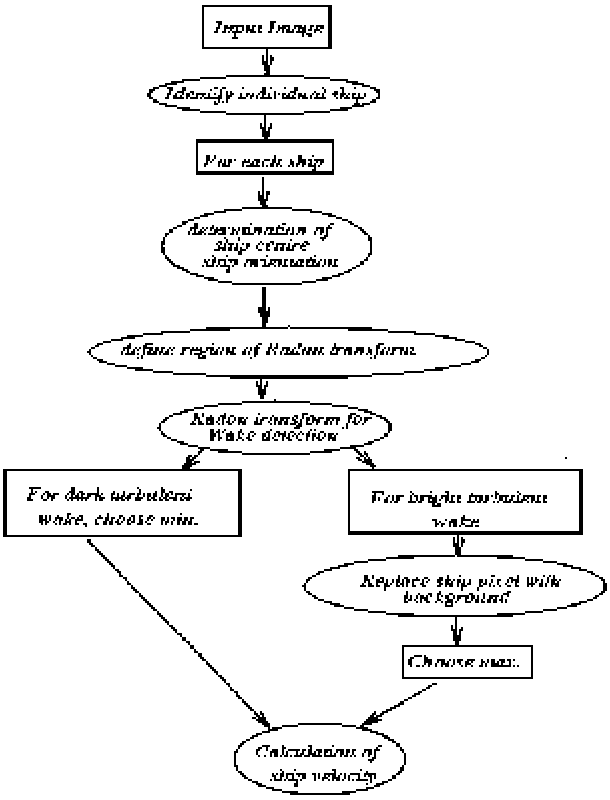

Figure 5: Basic structure of the detection algorithm...

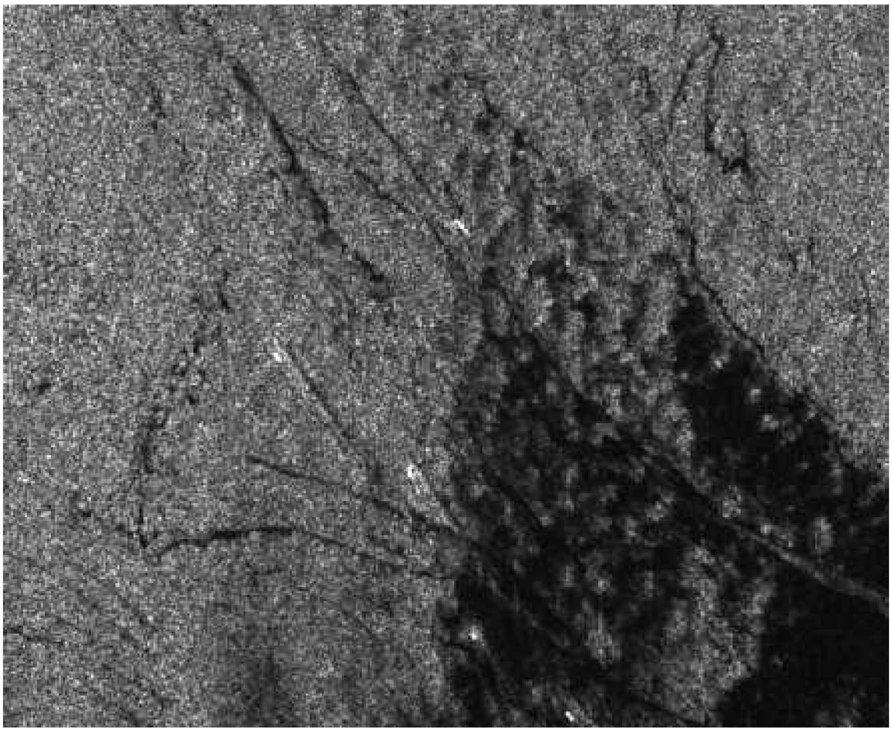

Figure 6: A typical ERS SAR imagery near the coast of Singapore containing ships (bright features) and the associate turbulent wakes (dark linear features).

1.6 Identification of Individual Ship:

The detection starts with the identification of ship. As discussed, ships are very bright features thus can be identified using simple thresholding technique. A moving window of size 100 pixel by 100 pixels is used. The moving window will run through the image and identify possible ships. For an 8-bit image, the threshold DN is set to be 250. The image DN at pixel coordinate (i, j) is defined as DN (i, j). If DN(i,j) ³ 250, DN(i,j) is identified as a ship pixel. A ship is considered to exist within the moving window if ship pixels exceed certain number, e.g. 5 ´ 5 = 25 pixels (corresponding to ship of dimension 5 pixel ´ 12.5 m/pixel =62.5m for ERS PRI imagery).

From all the ship pixels within the window, the coordinate of an initial ship centre is defined as $\boldsymbol{center\ i} =< i >$ and $\boldsymbol{center\ j} =< j >$. The next step is the removal of false ship pixels as some individual pixels may have DN greater than the threshold but does not belong to the ship.

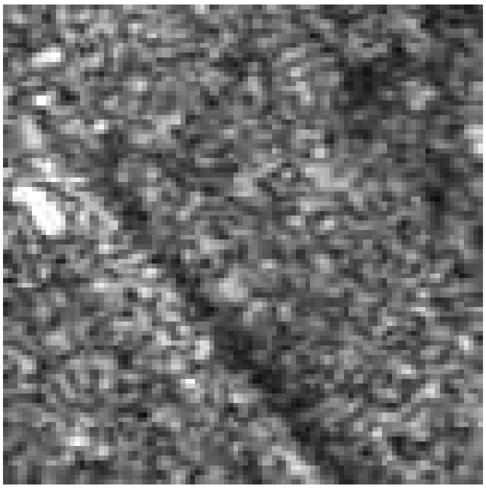

Figure 7: The actual image.

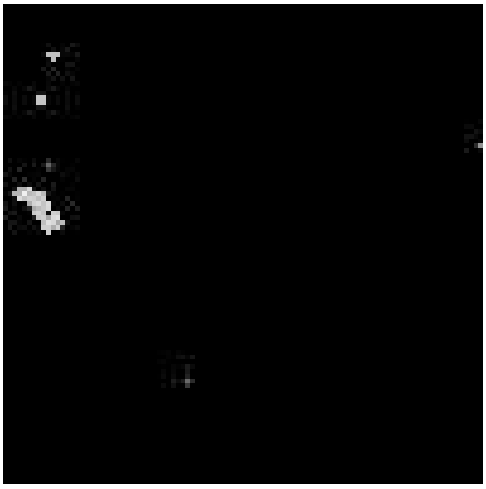

Figure 8: Enhanced image

1.7 Detection of ship orientation:

After eliminating the false ship pixels, the 'true' ship pixels are used to calculate the ship orientation. Given a set of ship pixels $(i_1, j_1)(i_2, j_2)(i_3, j_3)(i_4, j_4) \dots\dots\dots (i_n, j_n)$, we can use the method of least squares to determine the ship orientation (figure 8). The best fitted straight line for the above set of pixel pairs is given as $j = mi + c$.

$$m = \frac{\sum_{k=1}^{n} (i_k - i) j_k}{\sum_{k=1}^{n} (j_k - j)^2} \qquad (3.10)$$

$$c = \bar{J} - m\bar{I} \quad (3.11)$$

By calculating the slope m, the orientation of the ship can be obtained.

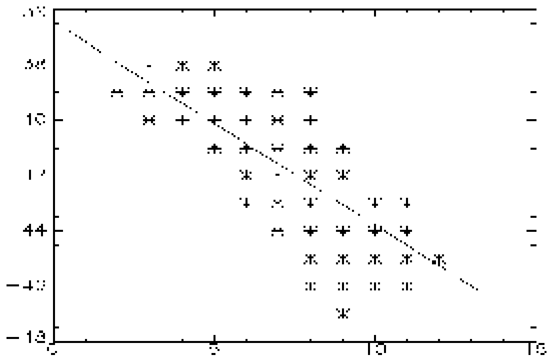

Figure: Ship pixels are plotted as scatter plot and the best fit straight line is drawn.

1.8 Wake Detection by Radon Transform:

Taking from the new ship centre, we can define a region for Radon transform (equation 3.9) to detect the corresponding ship wake. A region of size 120 pixel square is used (figure 3.9).

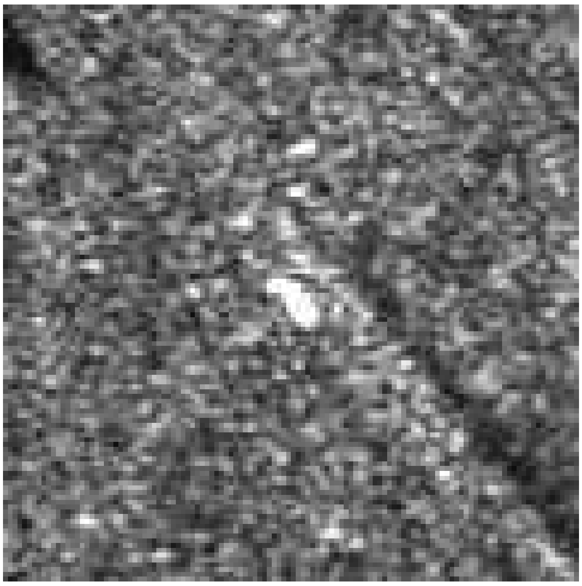

Figure 9: A 120 pixel by 120 pixel region for applying RADON transform centered at the new ship centre

1.9 Calculation of Ship Speed:

Once both ship and wake position is determined, the ship speed and heading can be estimated. Equation is re-written as

$$u = -\frac{1}{44}\left(\frac{\Delta}{|\cos\varphi|}\right) = -\frac{1}{44}\left(\frac{\rho}{|\cos\varphi|\sin\alpha}\right)$$

The negative sign is applied since equation is derived based on wake being the origin while ship becomes the origin in the Radon transform. The absolute of cosf is taken as the ship orientation determined by the method of least square is 180° ambiguous. The ship heading can only be determined using equation after $\boldsymbol{\rho}$ is determined.

1.10 SOVE Algorithm Technique:

This technique proposes a novel methodology for ship detection and their full velocity vector extraction from SAR data, using only the amplitude information. The algorithm is based on the Radon Transform to detect the ships and to retrieve the two components of the velocity vector at the same time, from the wake orientation and the azimuth displacement. The main advantages are that the algorithm does not need any a priori information and it is very light from the computational point of view.

Proposed Methodology:

Typical limitations of the proposed techniques are the incapability to estimate the full velocity vector of the ships without a priori knowledge and presuppositions that limit their applicability in a real context. Herein we propose a simple, robust and fast algorithm to detect the ships and estimate their full velocity without using any a priori knowledge, resulting in a very efficient velocity vector estimation algorithm using only the minimal informative content of SAR data. The basic principle of the estimation is the consideration of the ship orientation, from which the wake turbulence direction is derived, using the Radon transform. The method is structured in three steps, which allow to detect the ships present in the scene and to estimate their full velocity vector.

The main steps of the methodology are the following:

1. Ship detection;
2. Focusing of every detected ship and preprocessing;
3. Full velocity vector estimation.

SOVE Filter:

In this algorithm the developer suggested the special filter, called SOVE Filter which eliminates the unnecessary image components.

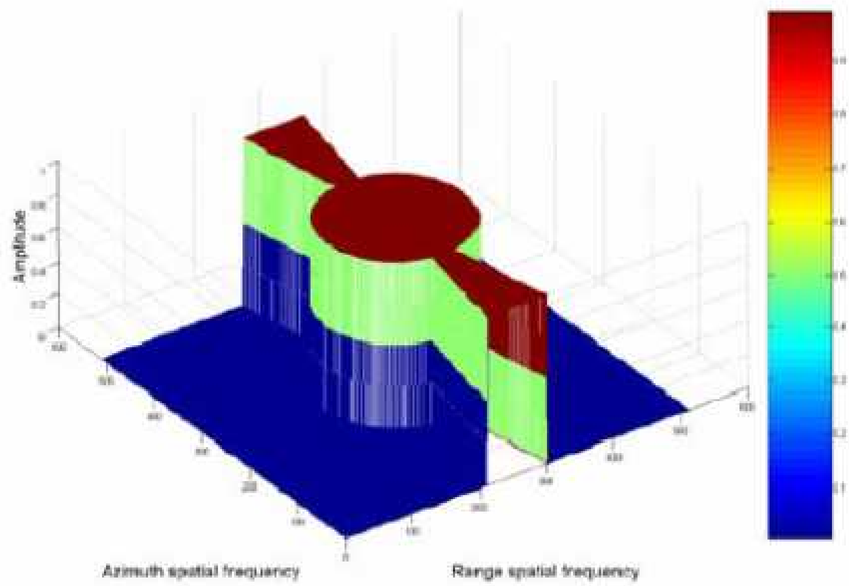

Figure-10: The SOVE Filter

SOVE filter is a spatial filter in which the surrounding part of necessary image component of the ship will be eliminated. To avoid strong distortions in the images, the filter does not cut the low frequencies. For the filter we chose the angle β=30° and the radius of the low pass filter R=20% of the image size. In fact, values of R lower than the 15% of the image size destroy the informative content of the scene. Note that all the pixels of the contour to the filter are set to 0.5, giving more continuity to the transition between the frequencies to pass and to filter.

Stochastic Matched Filtering Technique

Here, we introduce a method to reliably detect the Kelvin wake based on the analysis of its 2D spectral signature. The method uses a pre-processing step based on a generalized Radon transform (GRT) of the 2-D Fourier transform of the image. The result of the transform is then thresholded using stochastic matched filtering.

Implementation and Results

A graphical user interface has been developed using MATLAB software for the three techniques and the results has been compared with the real values of velocities and directions of the ship, which were collected by different satellite based SARs.

4.1. Graphical User Interface:

The developed GUI is capable of calculating ship Velocity and direction using the image and the SAR satellite data as inputs.

The step wise procedure to estimate the ship velocity and direction using the GUI is as below.

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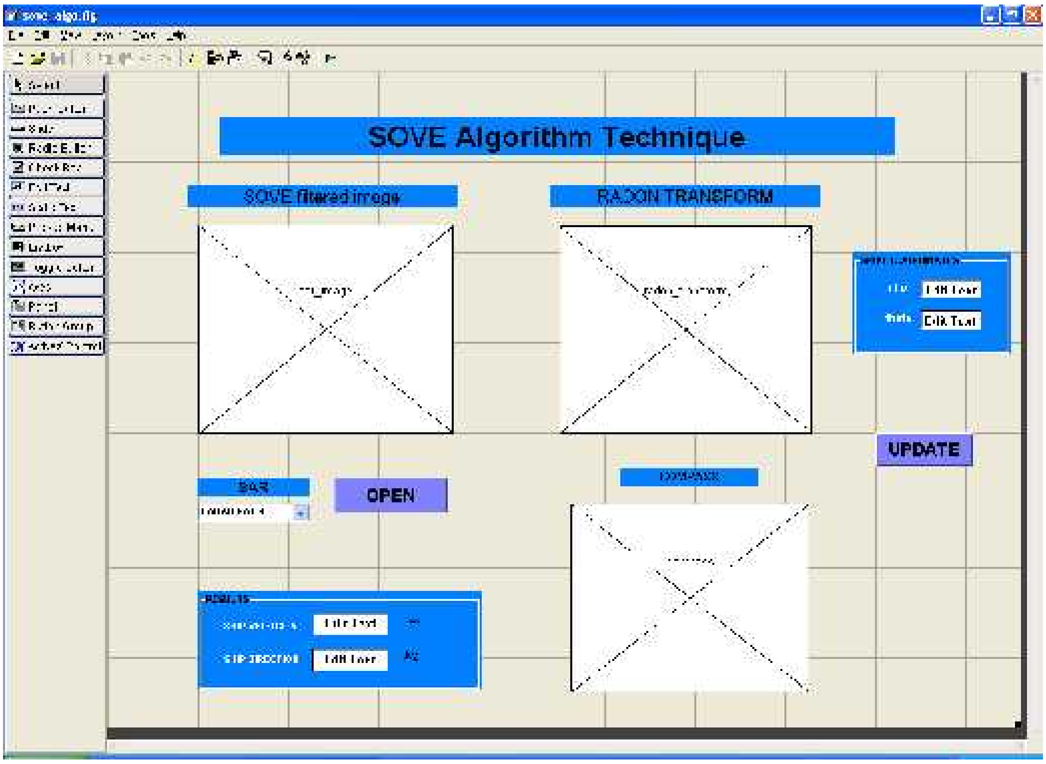


Figure-11: Graphical user Interface for SOVE Algorithm Technique

We collected some SAR images of ships and their corresponding velocities and directions and applied all the three methods on them using the GUI’s designed. One of the examples of collected images of different satellites is

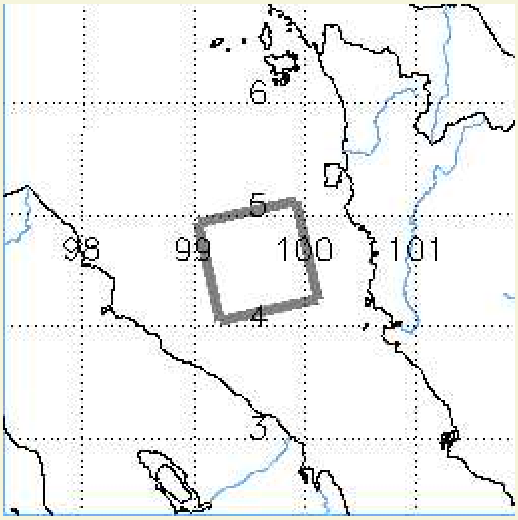
Image Data		**Strait of Malacca**
Date:	04-May-1996	
Time:	16:00	
Orbit:	25121	
Frame:	0081	
Satellite:	ERS-1	
Latitude:	4° 36' N	
Longitude:	99° 35' E	

Figure-12: One of the examples of collected images of different satellites

This image shows a 10 km x 12.6 km subsection of an ERS-1 SAR scene in the Strait of Malacca. A ship, its turbulent wake (partially dark band) and one arm of its Kelvin wake (bright line) can be seen.

Here is the stepwise Procedure of the Graphical User Interface

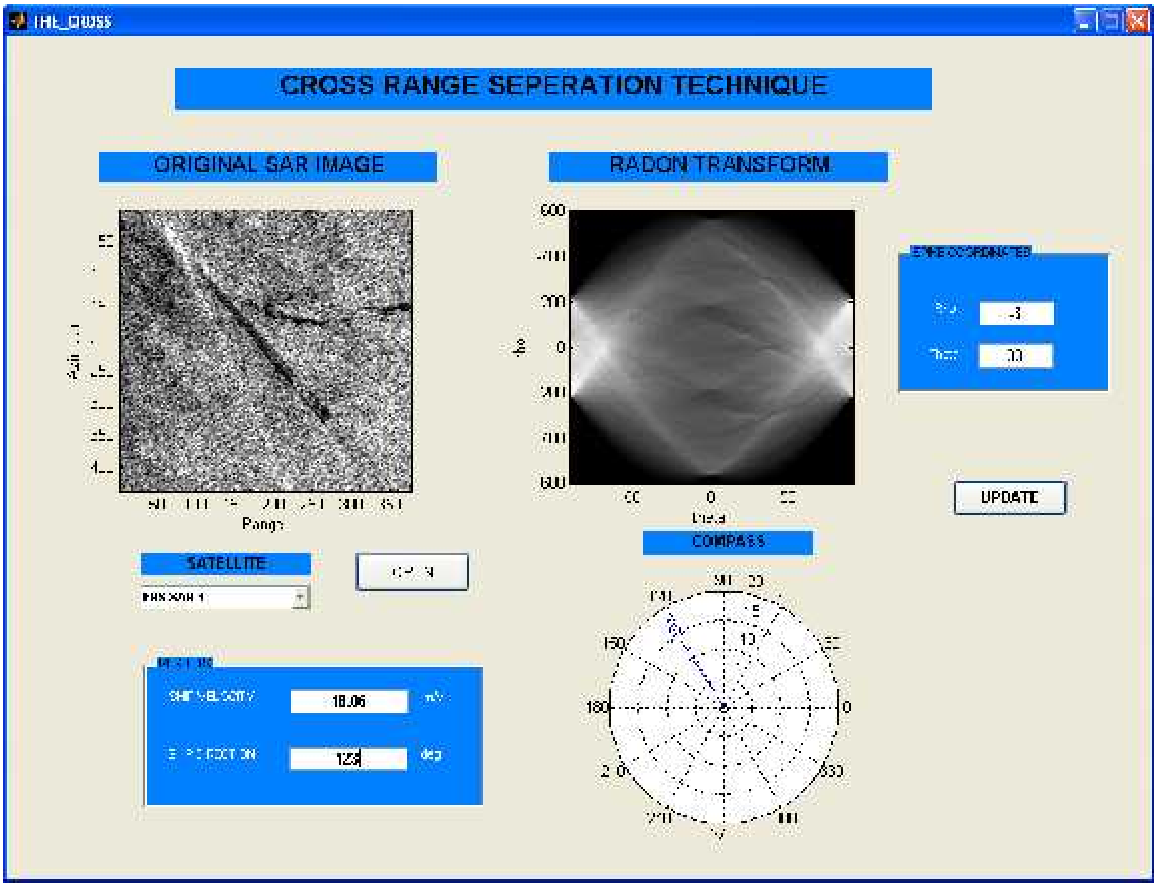


Figure-13: Cross Range Separation Technique.

Step1:

Click '**OPEN**' button.

A window of list of images appears as Figure-4.6

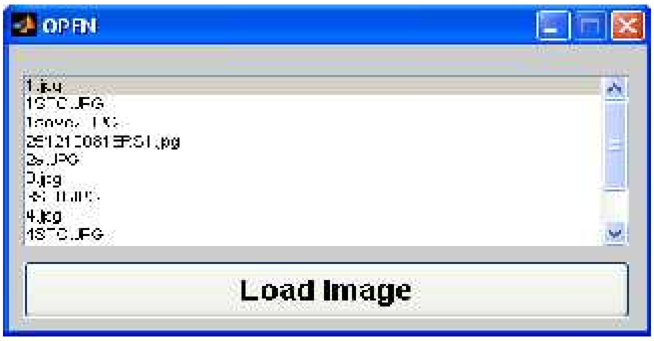


Figure-14: Open Window

Step2: Select an image and click '**Load Image**'. Then the selected image will loaded to the real image window.**Step3:** Select a satellite from the list bar. The Radon Transformed image will appear on the second window.**Step4:** Click on the second window to get figure of the image to Zoom and collect the spike points.**Step5:** Enter the spike values in the edit boxes and click '**UPDATE**'. Then the calculated values of ship velocity and ship direction will be appeared and the compass executes according to the values.

In this project we collected different SAR satellite images of ships and the corresponding satellite information and implemented all the three methods using the above Graphical User Interfaces.

SOVE Algorithm Technique:

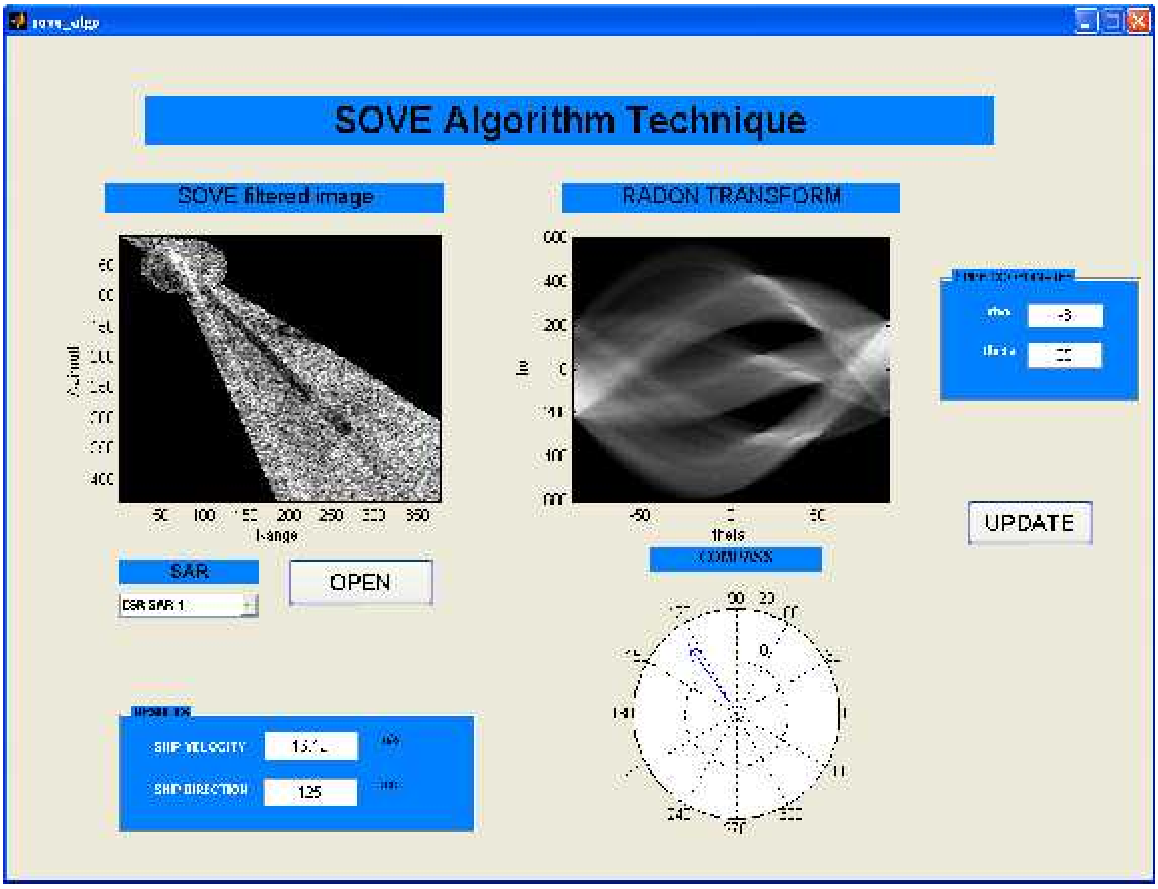


Figure-15: Result-1 of SOVE Algorithm technique

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All the above results are noted in a tabular form and the performance of all the above three techniques are compared with the real values, which are collected along with the images.

Tabular form:

1. Cross Range Separation Technique:

S.no	Image	Theta(deg)	Rho	Real Velocity(m/s)	Estimated Velocity(m/s)	Error (%)
1	09ERSSAR1	33	-3	21.49	18.06	15
2	02RADARSAT1	-30	42	11.52	9.93	13.8
3	425ERSSAR1	-22	3	12.2	9.42	22.78
4	08RADARSAT2	-25	-17	10.4	8.7	17
5	24ERSSAR2	51	-3	6.2	4.49	17.1
6	RADARSAT2	-23	-28	14.69	12.96	11.7

Table1Results of Cross Range Separation Technique

2. SOVE Algorithm Technique:

S.no	Image	Theta(deg)	Rho	Real Velocity(m/s)	Estimated Velocity(m/s)	Error (%)
1	09ERSSAR1	35	-3	21.49	19.12	12
2	02RADARSAT1	-30	1	11.52	9.25	12.8
3	425ERSSAR1	-21	3	12.2	8.24	20.44
4	08RADARSAT2	-22	-14	10.4	9.1	10.2
5	24ERSSAR2	50	-6	6.2	5.25	14.21
6	RADARSAT2	-26	-39	14.69	12.46	10.2

Table-2: Results of SOVE Algorithm Technique

3. Stochastic Matched Filtering Technique:

S.no	Image	Theta(deg)	Rho	Real Velocity(m/s)	Estimated Velocity(m/s)	Error (%)
1	02RADARSAT1	37	-1	11.52	8.92	11.2
2	09ERSSAR1	-31	32	21.49	15.02	10.4
3	08RADARSAT2	-21	2	10.4	9.5	9.2

Table-3: Results of Stochastic Matched Filtering Technique

1.11 Comparison of the Methods:

Cross Range Separation Technique:

The main advantages are simple and robust method. The disadvantages of this method are collecting spike from the Radon plane is difficult due to the noise effect. The region of the spike coordinates can be expected using the references only. There is no preprocessing or post processing technique suggested to increase the SNR of the Radon transformed image. No filters are used to increase the efficiency of the method. So the accuracy of the method is less compared to the other methods suggested. From Table-4.1, it can be observed that the percentage error is high when compared to the real values of the ship velocities.

SOVE Algorithm technique:

The main advantages are that the algorithm does not need any a priori information and it is computationally very light. From the simulations, the SOVE algorithm is very accurate and robust, failing only in extreme conditions. The region of the spike coordinates is easier to detect in this algorithm. To experiment the algorithm in a real context, we applied it in unfavorable scenes. Even under these conditions it produced very encouraging results. The SOVE Filter increases the efficiency of the Algorithm by removing noise from the image. It is the preprocessing technique where the SAR image is processed before applying Radon transform. However, we cannot eliminate completely the noise from the image to get higher accuracy comparing to the other post processing Techniques (Stochastic Matched filtering Technique).

Stochastic Matched Filtering Technique:

The main advantage of the method is its less noise. Collecting the spike coordinates is easier than the other Methods. Our approach is general, in that it can be used for SAR pictures, but also for optical images, provided that the Kelvin wake is visible, which means that the imaging configuration must have been designed for that task.

The GRT performs well in concentrating the energy of the wake but we observed it never performed better than the human eye, in that the wake spectrum had to be visible in the Fourier transform for the algorithm to have a chance to work.

This involves higher simulation costs, but once this is done, the SMF has exactly the same complexity as any linear filter and can be computed efficiently by a fast Fourier transform. There is therefore no reason not to use it to increase the robustness of the signal.

There are, however, restrictions to the method in that the depth of the sea must be infinite (otherwise the locus has a different expression, but this could be adapted) and the ship must not be turning (which smears the locus of the spectrum and precludes proper detection).

As for stochastic matched filtering, its originality is precisely to help improve the SNR when the signal is not known deterministically, but only through its covariance.

Conclusion

The estimation of ship heading and speed from a high resolution **Synthetic Aperture Radar (SAR)** image of ship and its wake is important for monitoring and tracking ships. In order to get a correct and focused image of the moving ships, it is necessary to know the real positions and velocities of the ships. Though the ship can often be imaged clearly, its orientation may be difficult to estimate from its image because of the effects of ship motion. The wake can provide direct information about the ship heading. The cross range separation between the location of the ship in the image and the wake can also provide an estimate of the ship's velocity. In this Paper all the three Simulation Methods were described and the Matlab based GUI was developed. According to the study of all the above results it is concluded that comparing all the three methods of estimating the ship velocity using raw SAR images the Stochastic Matched Filtering Technique is more effective than the other two because of its less percentage error even its complex.

Bibliography

1. K. Eldhuset, "An automatic ship and wake detection system for spaceborne SAR images in coastal regions", *IEEE Trans. Geosci. Remote Sensing*, vol. 34(4), pp. 1010-1019, 1996.

2. I-I Lin and V. Khoo, "Computer-based algorithm for ship detection from SAR imagery," http://earth.esa.int/symposia/papers/lini/, April 2003.

3. J. Lighthill, *Waves in Fluids*, Cambridge, 1980.