Vessel Detection and velocity estimation using SAR amplitude images

Duarte Carona, Paulo Marques
dcarona@deetc.isel.ipl.pt pmarques@isel.pt
Instituto de Telecomunicações, Av. Rovisco Pais 1, 1049-001 Lisboa, Portugal
Phone: +351-218418455, Fax: +351-218418472,
ISEL - Instituto Superior de Engenharia de Lisboa, Rua Conselheiro Emídio Navarro 1, 1959-007 Lisboa
Phone: (+351) 218 317 000, Fax: (+351) 218 317 001

***Abstract* - This paper presents a novel technique to detect ships and estimate their velocities. The technique takes advantage of two existing techniques and inserts some innovation by using the Radon Transform to detect the ship wake and estimate the range velocity component. For detection, cross correlation of split-look is used. To estimate the azimuth velocity component a sequence of single-look SAR images which are processed using look filters with different center frequencies are used. In these images, candidates for moving objects are detected and a displacement vector is performed for each candidate, therefore making possible the estimation of the ship velocity using amplitude SAR images.**

***Key words:* SAR, Detection, Velocity Estimation, Radon Transform, Multilook**

I. Introduction

The monitoring of vessel traffic is of big interest for countries with vast oceanic areas such as Portugal. The image obtained from SAR permits in an automatic way, to detect, to identify and to estimate their velocities as well as the corresponding navigation directions.

Synthetic Aperture Radar (SAR) is a powerful tool to obtain high resolution images from a wide area. If the illuminated area has a moving target then in the SAR image the target will appear defocused and misplaced [1]. If the target is moving in the azimuth direction a defocusing of the image occurs in the zone where the target is located; if the target is moving in the range direction it will appear misplaced in the azimuth direction [1].

For the ship detection the typical techniques take advantage of the pixel intensities. However these methods are not reliable because the sea can present a high degree of variation in the pixel intensities leading to a high number of false alarms [3].

This communication proposes a novel approach for the vessel detection that uses the high coherence of the pixel intensities in the case of ships. Therefore a 2D correlation between two or more looks can lead to the vessel detection in the area illuminated by the platform. The range velocity component can be estimated by detecting the ship wake [2] by using the Radon Transform and measuring its distance to the ship. The full velocity vector is estimated by using the ship wake orientation.

The images used have a length of 200m in azimuth direction and 200m in range direction, approximately.

II. Proposed Approach

A. Detection

Detection is performed by dividing the synthetic aperture in several bands and by processing a single-look for each band. Each single-look image will show the ground at different look angles and at different times [3]. If the SAR image does not contain any vessel then the single-look images will not show a high correlation due to the sea motion which leads to a very low coherence in each resolution cell for different times.

If a vessel is present there is a high correlation in the same region for different sub-images, even if the ship is moving. . Therefore, to detect a ship we use a two dimensional cross correlation function (2D-CCF) between two consecutive sub-images as proposed in [3]. Fig. 1 and Fig. 2 illustrate the aforementioned situations.

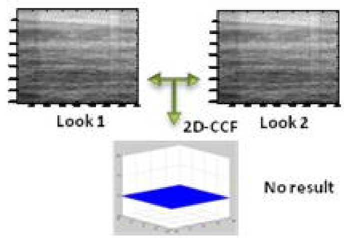

Figure 1 – 2D-CCF for an area which does not contains any ship

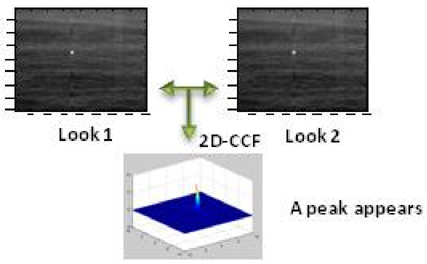

Figure 2 - 2D-CCF for an area which contains a ship

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Each peak found is called a candidate. For each candidate a displacement vector will be estimated using the method described below.

B. *Estimation of the Azimuth velocity component*

The displacement vector for each candidate in azimuth direction (Δx), will be determined by using the algorithm proposed [1], which estimates the displacement of a candidate between two consecutive sub-images, designated bellow by I_1 and I_2, using the following strategy:

- The candidate is centered in a window placed in I1 and I_2;
- The coordinate difference between the two windows gives the displacement vector of the candidate.

The azimuth velocity component is estimated through the displacement vector, where the difference in time between two consecutive sub-images is given by, [1]

$$\Delta t = \frac{\Delta\theta R_0}{V_{AX}}, \quad (1)$$

where $\Delta\theta = \theta_i$, $\sin\theta_i \ll 1$, V_{AX} represents platform velocity and R_0 the distance between platform and ground.
Each sub-image represents the same area at different look angles, defined as follows, [1]

$$\theta_i = \sin^{-1}\frac{f_{Li}\lambda}{2V_{AX}}, \quad (2)$$

where f_{Li} represents the center frequency of each sub-image.

The azimuth velocity component is then computed by [1]

$$V_{tx_{Obs}} = \frac{\Delta x.\delta_x}{\Delta t}, \quad (3)$$

where δ_x is the pixel spacing in azimuth direction, and Δt is the time for each look angle.

This velocity does not represent the real velocity because the objects appear in the images out of place, thus, as shown in [1] the real velocity is only half of the estimated in (3). The real velocity is given by

$$V_{tx_{ext}} = \frac{V_{tx_{Obs}}}{2} = \frac{\Delta x.\delta_x}{2\Delta t}\ . \quad (4)$$

From (1), (2) and (4), the azimuth velocity component is then computed by

$$V_{tx_{ext}} = \frac{\Delta x\ \delta_x\ V_{AX}^2}{\Delta f_{Li}\ \lambda\ R_0}\ . \quad (5)$$

C. *Estimation of the range velocity component*

To estimate the range velocity component we use the Radon Transform, which allows the ship wake detection [2]. By using the distance between the detected ship and the estimated wake the range velocity component can be computed as follows

$$V_r = \frac{\Delta a \delta_y V_{AX}}{R_0}, \quad (6)$$

where Δa is the distance between the wake and the ship and δ_y is the pixel spacing in range direction [4].

III. RESULTS

The proposed technique was applied to synthetic raw data, which contains a moving vessel and its respective wake. The focused image is presented in Fig. 3, where the vessel appears, as expected, with a displacement, relative to its wake. The parameters of the SAR mission are presented in table 1.

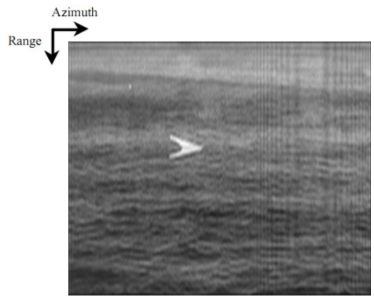

Figure 3 – Simulated image

A. *Range Velocity*

To detect the ship wake and estimate it's we use the Radon Transform to calculate the angle that a straight line perpendicular to the track makes with the x-axis in the center of the image. Knowing this, simply add 90º to the value obtained to find the angle of the wake arm. The other *arm* of the ship wake is processed in the same way.

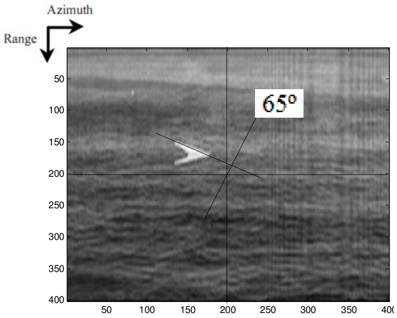

Figure 4 – Geometry used to calculate ship wake position

With the angle of both *arms* of the wake calculated, the equation of the line that passes by each of them can be estimated as follows

$$y = mx + b, \tag{7}$$

$$m = \tan\theta, \tag{8}$$

where θ is the angle that the arm makes with x-axis and,

$$b = \frac{d}{\cos(90-\alpha)}, \tag{9}$$

where d represents the point where the line that contains the ship wake passes through y-axis, and α is the angle perpendicular to the line containing the arm of the ship wake (obtained with Radon Transform). The vessel position is estimated as the point where both lines intersect.

Table 1 – Simulation parameters

Platform velocity (V_{AX})	250 m/s
Distance between platform and ground (R_0)	10 000 m
Pixel spacing in range direction (δ_y)	1 m
Frequency (f_c)	5 GHz
Pulse Repetition Frequency	250

The maximum speed that can be estimated using this method is imposed by the pulse repetition frequency (PRF) and is given by,

$$V_{r_{max}} = \frac{PRF \times c}{4 \times f_c} \tag{10}$$

The maximum speed in range is therefore 3.75 m/s (13.5 km/h). This limit can be increased by using other mission parameters.

The results of velocity estimation are presented in Table 2,

Table 2 – Estimated velocities

Real Velocity (km/h)	Estimated velocity (km/h)
1	1.10
2	2.20
3	3.40
4	4.50
5	5.60
10	11.20
13	13.80

From the analysis of Table 2 we can see that that the proposed method gives satisfactory results for many applications.

B. Azimuth velocity

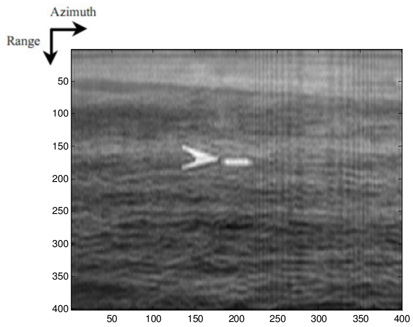

Figure 5 – Reconstructed image

Fig. 5 illustrates the effect caused by the azimuth velocity, namely a defocusing in azimuth direction as well as a small shift from his wake. This data will be used to generate the sub-images that enable the estimation of the azimuth velocity component.

After the generation of the sub-images a 2D-CCF is performed between two consecutive sub-images. The 2D-CCF result is present in Fig. 6.

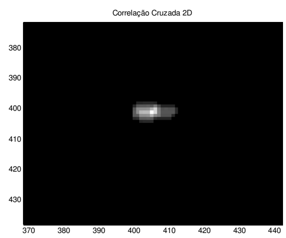

Figure 6 – Performed 2D-CCF

To estimate azimuth velocity component lack only calculate the center frequency of sub-images used to carry out cross correlation, thus, the frequency spectrum of each sub-image in azimuth direction was calculated.

After processing the coefficients of FFT, corresponding to the maximum of signal in frequency, it is possible to estimate Δf_{Li}, using (5), and consequently the azimuth velocity component. The estimation results are present in Table 3. From the presented results we can see that the azimuth velocity can be estimated with accuracy high enough for many applications.

Table 3 - Velocity estimation in azimuth direction

Real velocity (km/h)	Estimated velocity (km/h)
5	6.85
10	13.21
15	13.71
20	17.14
30	24

IV. CONCLUSIONS

In this communication, a novel technique that allows the estimation of azimuth and range velocity components of vessels is presented. The Radon Transform is used to detect the ship wake and estimate the range velocity component. The azimuth velocity component is estimated from a sequence of sub-images that show a specific region at different angles and consequently at different times. The velocities are estimated through the effect that is produced by vessel motion, i.e. a displacement in the azimuth direction, due to the ship range velocity, and a defocusing in the azimuth direction due to the azimuth velocity. The proposed method is able to estimate the velocity with accuracy high enough for many applications of interest. The major advantages of the proposed method, when compared with others published in recent bibliography are the low computational requirements and the fact that the algorithm works with amplitude SAR images. When compared with other methods, the proposed algorithm presents difficulties when the ship wake is not visible in the image. In this situation, the range velocity cannot be estimated

V. FUTURE WORK

As future work we aim to improve the estimation of azimuth velocity component. We also intend to test this method with real data.

VI. REFERENCES

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