AN AUTOFOCUSING ALGORITHM FOR POST-PROCESSING OF SYNTHETIC APERTURE RADAR (SAR) IMAGES BASED ON IMAGE ENTROPY MINIMIZATION

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Abstract

In this paper, a two-dimensional (2D) Synthetic Aperture Radar (SAR) geometry is presented for a ship target which is located on the sea surface. The ship is considered at first to be stationary, and subsequently an oscillatory movement is induced to its position along the vertical axis, due to sea surface motion. Moreover, the mathematical expressions of the backscattered signal (magnitude, and, in particular, phase) are presented for the two cases of a ship target mentioned above. Furthermore the 'CPI-split algorithm' [3] (CPI = Coherent Processing Interval) is applied in the SAR scenario examined here, and the numerical results, based on simulated radar data, are presented. These results show the effectiveness of the CPI-split algorithm [3] for the case of SAR imaging.

1. INTRODUCTION

Synthetic aperture radar (SAR) has been widely used for long-range imaging of stationary ground objects. This radar can perform with high image resolution at long range, regardless the weather conditions, because it is a radio frequency (RF) sensor. Hence, one of its main uses is in target detection and recognition for civilian or military applications. Provided that the target remains stationary, it is feasible from the SAR data to construct the target SAR image with high resolution by exploiting the range-Doppler information collected by the SAR antenna [1,2].

As far as moving targets are concerned, the reconstruction of the target image using SAR data is a more difficult task [1]. The SAR image of the target is usually defocused due to target movement. As moving targets are of great interest, the purpose of this paper is to apply the post processing CPI-split autofocusing algorithm [3] in the SAR geometry in order to get a focused SAR image of a moving target.

2. SIMULATED SAR GEOMETRY AND MATHEMATICAL FORMULATION

The simulated SAR geometry is presented in Fig. 1. The antenna of the radar, as it is common in SAR geometry, is mounted on a platform such as an aircraft and illuminates the target [1]. The aircraft is assumed to travel along a flight path from –N/2 to N/2 (N is the number of bursts during one CPI) with constant velocity v. The center of the flight path is considered to be the point A, as it is shown in Fig. 1. Furthermore, the radar is assumed to emit linear frequency modulation (LFM) pulses, where M stepped frequencies are emitted per burst (m=1 to M) and N pulses per CPI [1,2].

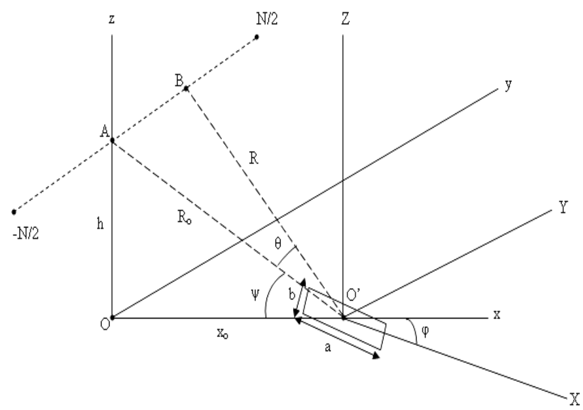


Figure 1. SAR geometry

The target is a ship on the sea surface with length and width b (2D geometry of the ship is assumed here, without loss of generality). The origin O' of the 'local' coordinate system [i.e. of the target (ship) to be imaged] is placed in the mass center of the ship. The distance R_0 is the distance between the center of the flight path and the origin O' of the local coordinate system. The angle ψ is the grazing angle of the incident radar electromagnetic (EM) wave and the angle θ is the angle of observation of the target within the CPI. The angle φ determines the orientation of the ship with respect to the 'earth' coordinate system Oxyz (axis Ox, in particular).

In the simulations of Section 3, below, the ship is considered in most CPI's of observation to be stationary. However, in some specific CPI's, an oscillatory movement is induced to its position along the vertical axis, due to sea surface motion. The SAR images that are obtained for these CPI's are blurred due to the ship movement. The main idea is to apply the CPI-split autofocusing algorithm [3] in order to eliminate the SAR image smearing.

In order to fully clarify the simulated geometry, the main mathematical expressions of the backscattered signal (magnitude, and, in particular, phase) are presented below, for the two cases of a ship target (e.g. stationary and in movement).

The backscattered radar data are simulated through the following formula:

$$x(m,n)=\sum_{d} s_{i,j}\exp[j\phi_{\mathrm{i,j}}^{\mathrm{m}}]+u(m,n) \quad (1)$$

where d is the number of the scatterers of the target and $s_{i,j}$ is the scattering intensity for the (i,j) scatterer. In the simulations below we can assume, without loss of generality, that all scatterers have the same strength in amplitude ($s_{i,j}$=1 for all i,j). The term $\varphi_{i,j}$ is the phase of the backscattered signal, while u(m,n) is the two dimensional additive white Gaussian noise component.

Assuming that the ship is stationary, the phase $\varphi_{i,j}$ for the (i,j) scatterer of the target, $\varphi_{i,j} = 2\underline{k} \cdot \underline{R}_{i,j}$, is calculated by our research group from analytic (geometric) calculation of the distance $\underline{R}_{i,j}$ between the radar and the (i,j) scatterer, and from the analytic expression for the incident wavevector $\underline{k}$, as well. These calculations lead to the following 'local' phase, assuming that the target is stationary:

$$\phi_{\mathrm{i,j}}^{\mathrm{m}}=\frac{4\pi \mathrm{f_m}}{\mathrm{c}}[\cos\theta\cos\psi(X_{i,j}\cos\phi+Y_{i,j}\sin\phi)+$$
$$+\sin\theta\cdot(X_{i,j}\sin\phi-Y_{i,j}\cos\phi)] \quad (2)$$

where m is the stepped frequency index (m=1,…,M); n is the burst index (n=1,…,N·N_{CPI}) for a number of simulated CPI's (N_{CPI}); N is the number of bursts during one CPI and ($X_{i,j}$,$Y_{i,j}$) are the local coordinates of the ship scatterers.

When the vertical movement of the ship, due to the sea motion, is taken into account, the phase formula changes. In the ship motion model, that we adopt here, an extra term is added due to the ship movement along the z-axis and it depends on the period T_{osc} of the oscillation. As a result, the phase of the backscattered signal is given by:

$$\phi_{\mathrm{i,j}_{osc}}^{\mathrm{m}}=\phi_{\mathrm{i,j}}^{\mathrm{m}}-\frac{4\pi \mathrm{f_m}}{\mathrm{c}}\mathrm{z}_0\sin(\omega_{\mathrm{osc}}\cdot t) \quad (3)$$

where z_0 is the oscillation amplitude and ω_{osc} is the angular frequency of oscillation.

In the numerical simulations of Section 3, below, the vertical movement of the ship is induced only for specific CPI's, where the raw data matrices are formed through Eq. (1) [dependence on 'slow – time' index n in eqns. (2) and (3) becomes effective through the aspect angle θ].

The SAR images for all CPI's are constructed from the raw data matrices through the traditional 'Range – Doppler' imaging technique, involving FFT processing in both range and Doppler directions [2]. In order to compare the quality of the SAR images obtained, the entropy values of each image are computed. It is expected that the SAR images which correspond to those specific CPI's in which the ship movement is induced, will have greater entropy values than the SAR images corresponding to no ship movement.

3. NUMERICAL RESULTS

The simulated ship geometry is shown in Fig. 2. It is a point scatterer model which consists of 233 scatterers. The corresponding radar and geometry parameters are shown in Table 1.

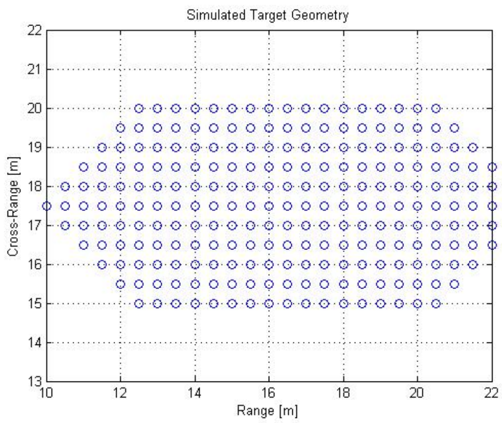


Figure 2. Geometry of the simulated ship target

The CPI-split autofocusing algorithm [3] is employed in those CPI's whose entropy values exceed a threshold that represents an acceptable SAR image quality. The images with entropy values below the entropy threshold are called "focused" images, while the images with entropy values over the threshold are called "unfocused". In this simulation scenario the value of the entropy threshold was set equal to 6.0 [3].

Table 1. SAR simulation parameters

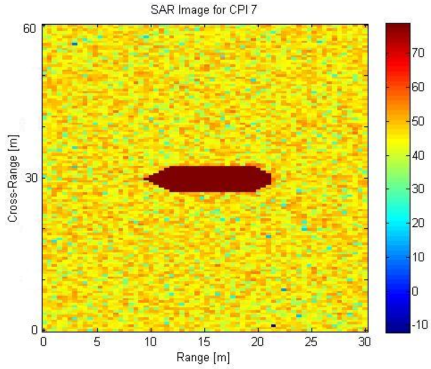
Parameter	Value [units]
carrier frequency, f_0	10 [GHz]
radar bandwidth, B	300 [MHz]
number of frequencies, M	64
frequency step, Δf	4.76 [MHz]
pulse repetition frequency, PRF	2.74 [KHz]
burst duration, T_b	0.0234 [sec]
coherent processing interval, CPI	3 [sec]
number of bursts, N	128
number of CPIs, N_{CPI}	13
range distance to center of target, R_0	10 [km]
height of SAR platform, h	2 [km]
position angle of the ship, φ	0°
velocity of platform, v_p	100 [m/sec]
oscillation amplitude, z_0	0.2 [m]
oscillation period, T_{osc}	1.3 [sec]

In this simulation, the flight duration is considered to be 13 CPI's. The ship movement is induced only in the 4th and 8th CPI. In Fig. 3, four (4) SAR images are presented. Images 3a, 3b and 3c represent the reconstructed SAR images for the 7th, 8th and 9th CPI respectively. It is clear that the SAR image of the 8th CPI (image 3b) is unfocused due to sea motion, as modeled in our simulations. In image 3d the SAR image of the 8th CPI is shown after the application of the CPI-split autofocusing algorithm [3]. Clearly the SAR image is now focused and has an acceptable entropy value. The CPI-split autofocusing algorithm is effective in this simulation scenario.

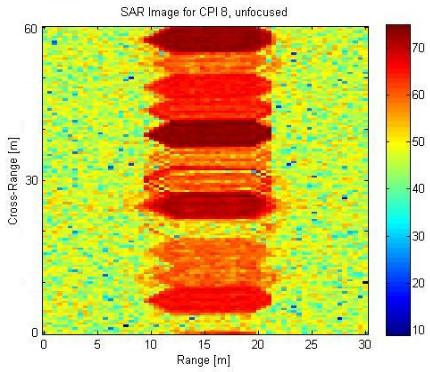
In Table 2 the entropy values for the CPI's related to the application of the algorithm are presented. Note that the entropy values of the 4th and 8th CPI are within the acceptable entropy value range (e.g. below the entropy threshold), after our proposed algorithm is applied [3].

Table 2. Entropy values of SAR images

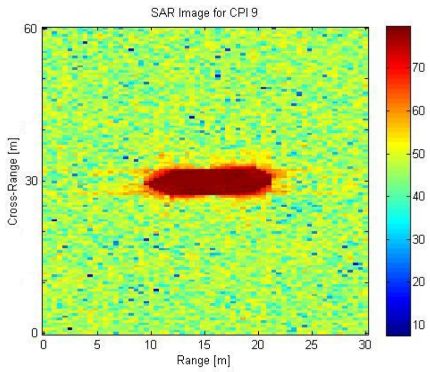
SAR Image	Entropy	Minimum Entropy Combination
3rd CPI	5.7635	
4th CPI, unfoc.	7.8581	
5th CPI	5.7540	
4th CPI, foc.	5.7648	stage 3, segment 1, comb. 1
7th CPI	5.6786	
8th CPI, unfoc.	7.3654	
9th CPI	5.7572	
8th CPI, foc.	5.7581	stage 3, segment 2, comb. 4



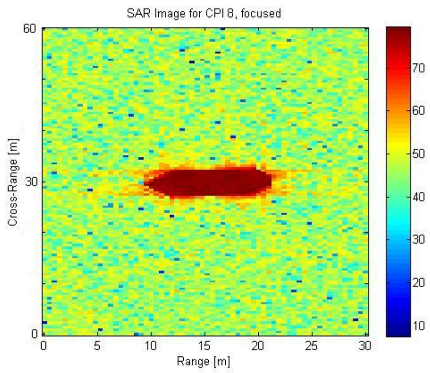
3a)



3b)



3c)



3d)

Figure 3. Reconstructed SAR images for the: a) 7th; b) 8th; c) 9th; CPI and d) the 8th CPI after application of the CPI-split algorithm

4. CONCLUSION – Future Research

In this paper, a 'CPI-split autofocusing algorithm' [3] is applied to a Synthetic Aperture Radar (SAR) scenario. The simulation results presented above show that the proposed algorithm is effective in producing focused SAR images, at least for the simulated data used in this research. One basic idea for near future research of our research group is to incorporate the proposed 'CPI-split autofocusing algorithm' also for the cases of real – field data.

References

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