Multi-Channel Segmentation of Moving Objects in Along-Track Interferometry Data

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ABSTRACT

The multi-channel capability of the AER-II sensor (airborne experimental radar) was used to measure radial velocities by along-track interferometry. The phase difference between two receiving channels with displaced phase centers in flight direction were used to calculate radial velocities. The phase information is often severely disturbed, in the case of a low signal to noise ratio. Additionally, moving objects are displaced in a SAR image depending on the radial velocity component. In this paper we refer to investigations to stabilize and improve the SAR-MTI analysis for very slow moving objects. The reliability of the velocity measurements are enhanced by a combined exploitation of phase and intensity. Furthermore the capability of a 4 channel SAR system to use different channel combinations for the velocity measurement is investigated.

1 INTRODUCTION

The airborne surveillance of traffic stream in extended areas becomes for civil and military applications more and more important. For this application the detection of slow moving objects e.g. ships, tanks and trucks is a very difficult problem for a MTI (Moving Target Indication) system on a moving platform, due to the problem of separating the signal of the object from the stationary background (clutter) by its doppler frequency [1], [2]. For some applications it is sufficient to choose a radar with a very high pulse repetition frequency and a narrow azimuth antenna beam. But if also a high quality ground mapping is desired a SAR system with MTI capabilities is a quite better choice. Nevertheless in the case of a SAR system additional problems occur, because the doppler frequency of the reflected signal is used for the enhancement of the azimuth resolution. The literature concerning this problem is extensive and the investigated approaches are very divers (e.g. [3], [4], [5], [6], [7], [8], [9]). An enhanced statistical analysis of the SAR raw data or a direct subtraction of the ground clutter in multi-channel systems with displace phase center antennas (DPCA) are typical attempts.

For very slow moving ground objects (e. g. velocities beyond 15 km/h) an interferometrical evaluation is promising [10]. The necessary data is taken by the a SAR system with at least two antennas or subapertures positioned parallel to the flight direction. The data is are processed coherently to obtain fine resolution information regarding the velocity of scene objects (along-track interferometry). In contrast to across-track interferometry allowing multi and single pass modus the interferometrical detection of moving objects is only possible in single pass modus. The main field of other investigations concerning along-track interferometry is regarding the measurement of radial velocity fields to identify ocean surface or coastal currents e. g. [11], [12], [13], [14].

Nevertheless the number of available high resolution SAR-systems with interferometric capabilities is increasing. These systems offers an additional utilization concerning for the surveillance of slow traffic streams.

The velocity is proportional to the phase difference of the complex SAR images. Especially in areas with low SNR respectively poor coherence the phase information is severely disturbed. Hence, the noise component has to be removed or at least significantly reduced before further analysis. This smoothing is frequently done by low pass filtering with sliding windows. Unfortunately, filtering results in a reduced geometric resolution and blurs signal jumps at object boundary.

In this paper a combined iconic and symbolic (model-based) approach to improve the phase differences is proposed. This method is supported by a joined analysis of the phase and the intensity information.

Our approach for the analysis of along-track interferometry data is comparable to the InSAR evaluation described in [15] and [16]. The methods differ mainly due to the different nature of the expected objects – cargo ship instead of roads and buildings. In both cases a combined segmentation in the phase differences and intensities is carried out, to detect areas containing candidates for objects. Afterwards, the phase differences of appropriate objects are smoothed. In this step the phase differences are weighted with their related intensity or coherence value.

The used data were recorded by the airborne AER-II experimental multi-channel SAR system [17, 18] of FGAN. This system is equipped with a active phased array antenna and up to 4 receiver channels. The center frequency of this X-band system is 10 GHz with bandwidth of 160 MHz. The ground resolution achieves a spacing of approximately 1m x 1m. The paper is organized as follows. First, we introduce in chapter 2 our approach for modeling and segmentation of scene objects. First results using different receiver channel combinations are presented in chapter 3. Chapter 4 gives a short summary and assessment of the achieved result.

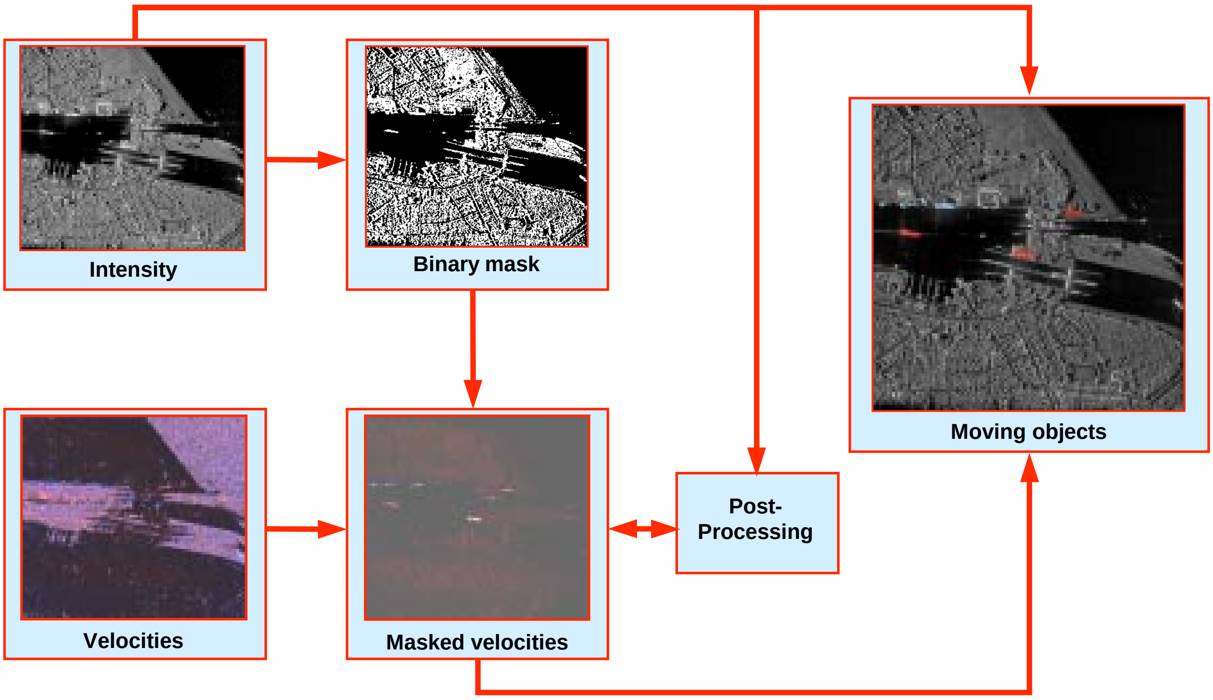

Figure 1: *Workflow for the segmentation of moving objects in along-track interferometry data*

2 APPROACH: MODELING AND SEGMENTATION OF SCENE OBJECTS

The presented approach of a combined evaluation of intensity and phase information presume that only image areas, which show a significant high intensity are suitable for calculations of reliable velocity values. Assuming that high intensities are correlated with high SNR, image areas with low intensities are masked before further processing.

The workflow of the evaluation process for along-track interferometry data is illustrated in figure 1. On the left side of figure 1 the input of the workflow- the intensity image and the phase differences, are depicted. The SAR raw data processing provides complex data from two channels, which are used two calculate the interferogram, intensity, phase differences (~velocities) and the coherence.

The desired task for this scenery (see figure 1) is to identify slowly moving cargo ships on inland waterways, which are entering or leaving the vicinity of a lock. The velocities of the ships can be expected to be in a well defined and comparatively low range. Our application deals with the problem to observe such slowly moving traffic streams with an airborne SAR working in along-track modus.

The approach combines a straightforward segmentation and rule based reconstruction of complex objects. It takes benefit of object features which appear different in intensity and phase. Hence, a combined analysis improves the reconstruction quality, due to accumulation of hints to objects in both channels. After speckle filtering a binary mask is generated from the intensity data. This mask is used to fade out regions with insufficient signal to noise ratio (e.g. water). For every point in the intensity image the radial velocity is calculated by the phase difference of at least two of 4 channels (see chapter 3). This image of velocities is masked with the binary image derived from the intensity image. A segmentation process is initiated in the velocity image to identify adjacent regions in the image with similar velocity. By this process first hints for moving objects are created.

The parameters of the segmentation process are adjusted by context and object information given by the model of the object. The modeling process of the scene objects is described in more detail in [19]. First a segmentation of primitive objects is carried out. For each of these objects a feature vector is calculated. Suitable features are related to geometric segment properties - for example length, width, compactness, elongation and rectangularity - or to radiometric properties, like mean and variance of intensity. The object primitives are classified and merged if specific constraints concerning geometric neighborhood and phase differences are met. The result is a set of hypotheses fulfilling the requirements derived by our object model.

The phase differences can now be restored for each object separately. The information about the object extension allows to determine a mean phase difference by a simple averaging process over all values inside the object boundaries. The average value corresponds to a Maximum-Likelihood estimate if the undisturbed values were originally the same and no phase ambiguities occur. Since ships are rigid constructions this assumption is valid in many cases. The averaging process should be carried out

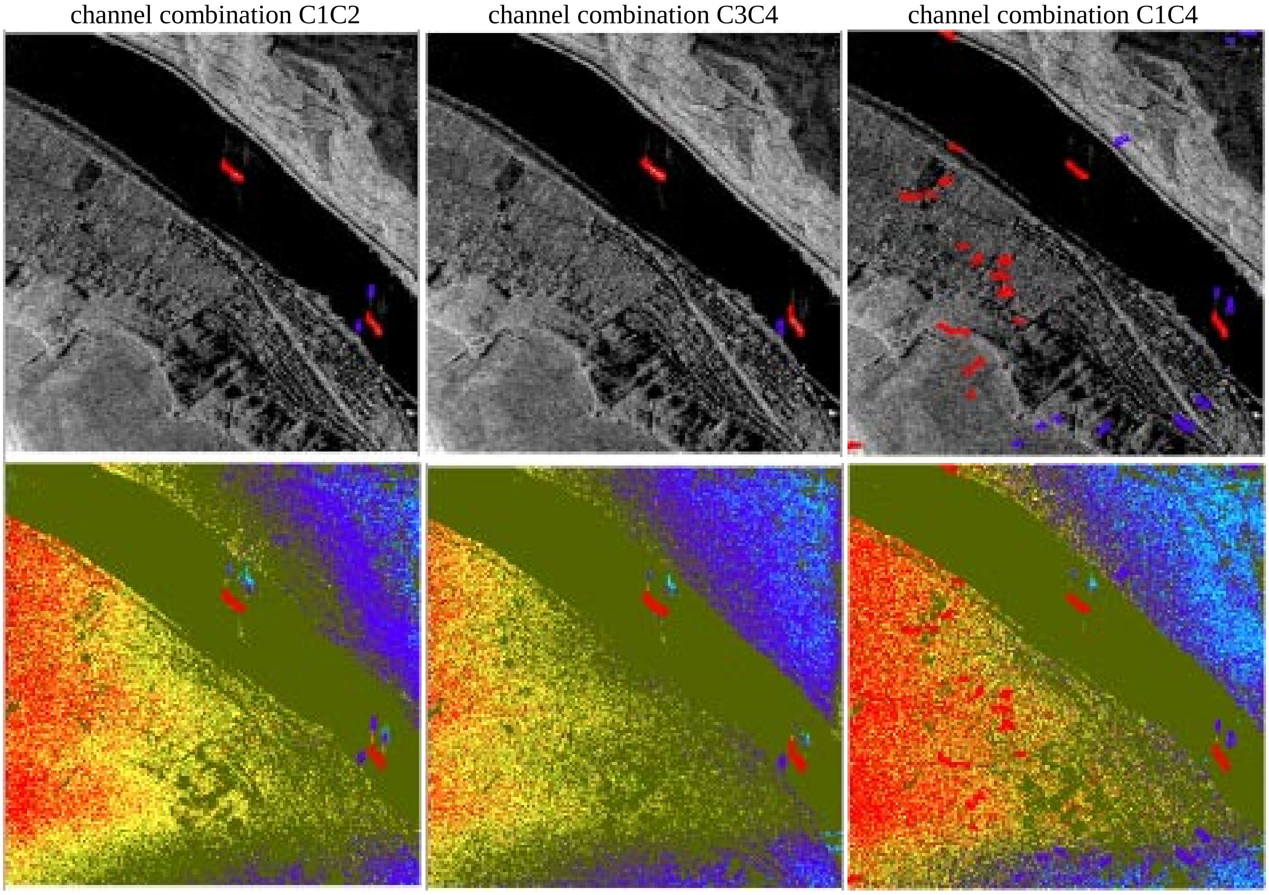

Figure 2: *The upper row shows the segmentation result for different channel combinations as overlay on the intensity image and the lower row shows the corresponding phase differences (pseudo color scheme)*

on the original complex data or directly on the phase values with suitable weighting factor. Because of its dependency to the SNR, the coherence or the intensity were used as weighting factor for this smoothing step.

3 EXTENSION TO MULTIPLE CHANNELS

The AER-II sensor system allows to use four different sub apertures of the phase array antenna according to 4 receiver channels (C1, C2, C3, C4) for the along-track interferometry. Depending on the channel combination different baselines can be realized. The multi-baseline ability is helpful to resolve velocity ambiguities and for a more effective clutter suppression. For this reason a test scenery was choosed with suboptimal motion compensation. The upper row in Figure 2 shows the segmentation result for different channel combinations as overlay on the intensity image. The scenery contains an inland waterway with 2 moving cargo ships. The lower row depicts the corresponding phase differences (velocities) in an pseudo color presentation (red indicates positive and blue negative velocities). The phase distribution of the ground in the scenery shows a systematical deviation. This distortion leads to a couple of false alarms for the channel combination C1C4. The channel combination C1C4 allows a maximum baseline of about 60 cm, which results in an unambiguous velocity interval of nearly ±10 km/h. This channel combination provides the best velocity resolution and is very sensitive. With the channel combinations C1C2 and C3C4 a baseline of approximately 20 cm is realized, which is in accordance with an unambiguous velocity interval of about ±30 km/h. Nevertheless the searched cargo ships are detected in all investigated channel combinations. The object based segmentation approach allows a combined evaluation of the single results and is used to enhance the evidence of the cargo ship hypotheses.

4 SUMMARY

The presented approach of a combined evaluation of intensity and phase information shows promising results for a detection and velocity estimation of single objects located at the ground or water surface. The approach was applied to images with slow moving cargo ships. The cargo ships are segmented and classified by a model based approach. Only cargo ships with a minimum velocity which match the longitudinal and transversal extension features of the model are considered in further processing. For every object a weighted average velocity is calculated. This procedure was carried out for several channel combinations and a combined evaluation of the single results was applied.

All objects in the scenery matching the model parameters were segmented. For one of the objects a rough estimate of the object velocity by the azimuth displacement shows a sufficient agreement with the measurement results based on the evaluation of the phase difference. An improvement of velocity determination was obtained by investigation of multi-channel data. For the present, the method is limited to tasks for which the implemented simple model is discriminating, but with the increasing quality of the available SAR data this techniques offer a broad potential for further applications.

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