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An extended chirp scaling algorithm for spaceborne sliding spotlight synthetic aperture radar imaging

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Abstract A system impulse response with low sidelobes is critical in synthetic aperture radar (SAR) images because sidelobes contribute to noise and interfere with nearby scatterers. However, the conventional tricks of sidelobe suppression are unable to be exactly applied to the case of spaceborne sliding spotlight SAR due to great azimuth shifts in both time and frequency domains. In this paper, an extended chirp scaling algorithm is presented for spaceborne sliding spotlight SAR data imaging. The proposed algorithm firstly uses the spectral analysis (SPECAN) technique to avoid the azimuth spectrum folding effect and then employs the chirp scaling (CS) algorithm to achieve data focusing, i.e., the so-called two-step approach. To suppress the sidelobe level, an efficient strategy for the azimuth spectral weighting which only involves matrix multiplications and short fast Fourier transformations (FFTs) is proposed, which is a post-process executed on the focused SAR image and particularly simple to be implemented. The SAR image processed by the proposed extended CS algorithm is very precise and perfectly phase-preserving. In the end, computer simulation results verify the analysis and confirm the validity of the proposed algorithm.

1. Introduction

The main characteristic of a synthetic aperture radar (SAR) sensor operating in the sliding spotlight mode is that the velocity of antenna footprint is lower than the platform velocity. It indicates that the azimuth scene size is larger than that in the pure spotlight mode and smaller than that in the classic stripmap mode.[1–3] On the contrary, the azimuth resolution is lower than that in the spotlight mode and higher than that in the stripmap mode. Similar to the pure spotlight mode using a real rotation point at the scene center, the sliding spotlight mode uses a virtual rotation point which is further away from the radar than the scene being illuminated.[4,5]

It is remarkable that two operational spotlight modes of the German TerraSAR-X are both designed in a sliding geometry with 1 m and 2 m azimuth resolutions at 5 km and 10 km along

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track scene extensions, respectively.[6–8] Similar to the pure spotlight mode, the azimuth spectrum folding effect also exists in the spaceborne sliding spotlight mode, and there are two available methods that can overcome this problem, i.e., the subaperture-division approach[9,10] and the spectral analysis (SPECAN) technique.[11,12] An extended chirp scaling algorithm based on the subaperture-division approach has been upgraded for data processing of the TerraSAR-X sliding spotlight SAR, and the Doppler histories of individual scatterers at different ranges and azimuth positions have been discussed in detail.[13–15] It is well known that a system impulse response with low sidelobes is of great importance in SAR images because sidelobes contribute to noise and may interfere with nearby scatterers. The theoretical values of the peak sidelobe ratio (PSLR) and the integrated sidelobe ratio (ISLR) without sidelobe suppression (i.e., rectangular window weighting) are −13.2 dB and −9.7 dB, respectively,[16,17] which do not meet practical requirements. Therefore, it is necessary to perform sidelobe suppression with the aim of achieving SAR images of high quality. For spaceborne sliding spotlight SAR, conventional sidelobe suppression methods can be used to achieve good results in the range direction, but fail in the azimuth direction due to great azimuth time and spectral shifts. Fortunately, a new azimuth scaling approach which is also based on subaperture-division, called baseband azimuth scaling (BAS),[18] has been developed for spaceborne sliding spotlight SAR. The subaperture-division approach takes the advantage of the higher pulse repetition frequency (PRF) relative to the instantaneous azimuth bandwidth, and some overlap (e.g., 5%) is needed to achieve a smooth subaperture recombination. Note that, reducing the PRF will alleviate the payload of a satellite, however, if the PRF approaches to the instantaneous azimuth bandwidth, each subaperture will contain very small samples and a large number of subapertures will be formed, so some problems will occur. First is the added computation, and second is that the azimuth time bandwidth product of each subaperture may not satisfy the principle of a stationary phase which is usually used to evaluate the phase compensation functions in the data processing procedure. This means that some operations are inaccurate and consequently result in a poor image.

In this paper, we present an alternative algorithm for SAR imaging that eliminates the problem of subaperture-division. We firstly use the SPECAN technique to avoid the azimuth spectrum folding effect and the chirp scaling (CS) algorithm[19,20] to achieve data focusing, i.e., the so-called two-step approach. Then we propose a novel strategy for the azimuth spectral weighting, which is executed on the focused SAR image. The focused azimuth signal is divided into segments in the image domain, and then each segment is transformed into the frequency domain to perform the spectral weighting. Finally, the whole weighted signal is obtained by the recombination of the weighted segments. Obviously, it is a post-process of the original SAR imaging process which only involves matrix multiplications and FFTs, so it is not only precise and simple to be implemented but also very efficient; furthermore, it is a perfectly phase-preserving process.

This paper is organized as follows. In Section 2, we give the principle of the proposed algorithm for spaceborne sliding spotlight SAR imaging. Section 3 is dedicated to analyze the two key points of the proposed azimuth spectral weighting strategy. Section 4 provides simulation results which verify the analysis and confirm the validity of the proposed algorithm. Section 5 concludes this paper.

2. Principle of the proposed algorithm

The geometry of the standard sliding spotlight mode[21] is shown in Fig. 1, where x and r are the velocity and range axis, V is the platform velocity, V_{f} is the antenna footprint velocity, and R_{s} and R_{rot} are the broadside slant ranges to the real scene center and to the rotation point, respectively. The system is operating in the broadside mode, and the illumination starts at position X_{start} and ends at position X_{stop}. During the data acquisition time, the radar antenna, which transmits pulses of a linear FM chirp signal with a chirp rate of γ, is steered to the virtual rotation point.

The characteristic of the Doppler histories is shown in Fig. 2, where t_{a} and f_{a} are azimuth time and frequency, respectively. From Fig. 2, two main inconveniences arise in the sliding spotlight mode. First is the azimuth spectrum folding effect due to the PRF being much smaller than the total azimuth bandwidth. Second is the azimuth sidelobe suppression. As is well known, convolution in the time domain is equivalent to

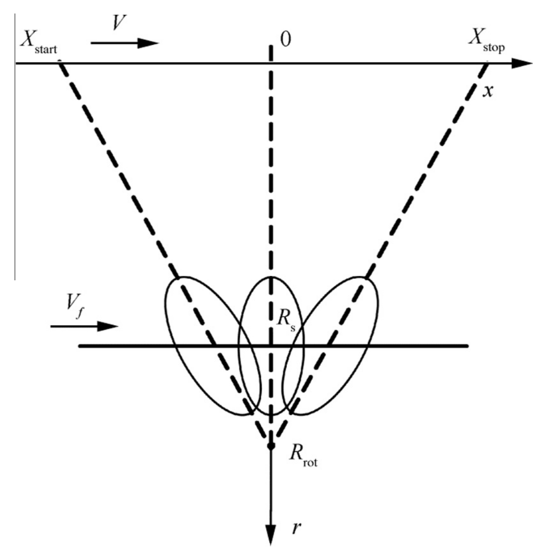

Fig. 1 Geometry of the standard sliding spotlight mode.

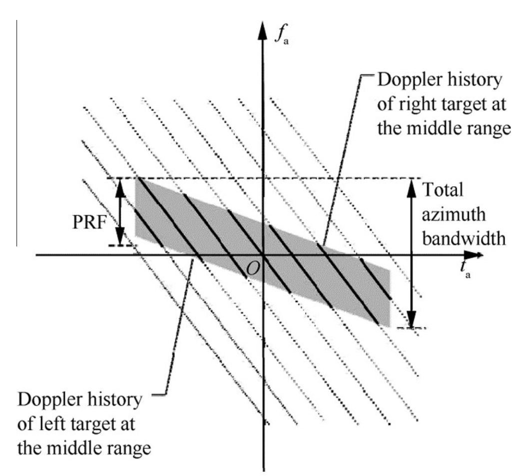

Fig. 2 Doppler histories of the sliding spotlight mode.