High Quality Spotlight SAR Processing Algorithm Designed for LiteSAR Mission

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Abstract -- A high quality spotlight SAR processing algorithm is presented. In this algorithm, subband **images** of **the radar illuminated** spot are processed using well known strip mode processing algorithms. A full resolution image is then formed by (1) merging the spectra of subband images into a full band spectrum, and **(2) taking** an **inverse** FFT. **Advantages** of this algorithm include (1) higher image quality, (2) higher processing throughput rate, and (3) lower S/W development cost. The image quality achieved by this algorithm is better than that previously achieved by the backprojection algorithm. The fine image quality is demonstrated by the SIR-C' spotlight SAR images.

INTRODUCTION

LiteSAR is a new program aimed at validating key advances in synthetic aperture radar (SAR) technology, and related systems, that will reduce the cost and enhance the performance of this and future U.S. SAR missions. To boost commercial interest in LiteSAR program, the LiteSAR is designed to be capable of many imaging modes including a high resolution spotlight SAR mode. Developing a spotlight processing algorithm suitable for the LiteSAR platform and meeting its requirement is one of the high priority task in the present project phase.

The concept of Spotlight SAR has been previously related to computed tomography [1]. The similarity between a spotlight SAR and an X-ray computed tomography (CT) system includes: (1) both are problems of reducing image sample values from measurements of signal strength from line integrals, (2) imaging areas are spatially bounded. The difference between these two systems includes: (1) the radar is operated with a coherent signal with a carrier frequency usually higher than its bandwidth, where the X-ray CT system is operated with non coherent signal and its equivalent bandwidth is determined by the width of X-ray beam contained in each detector, (2) in spotlight SAR, the line integral is defined along the segment of a circle, where in the X-ray CT system, the line integral is defined along a straight line.

Despite their difference, tomography processing algorithms such as convolution backprojection [2] and Inverse Fourier transform on polar spectrum [1] have been applied to spotlight SAR processing-. Previous reports showed that the image quality achieved by backprojection is generally better than the Inverse Fourier method. This is because that the polar spectrum is formed based on the approximation that the iso-range lines running through the radar spot approach straight lines. But, this approximation is not needed in the backprojection algorithm. in the LiteSAR system, the curvature of the iso-range lines is on the order of ten slant range resolution cells. Therefore, it is obvious that Inverse Fourier method will not meet the image performance requirement of the LiteSAR mission. Furthermore, the convolution backprojection algorithm is also not considered for its lower throughput rate. Instead, a new spotlight processing algorithm based on synthesis of subband image spectra, to be described below, is found to be a good canal idate for processing LiteSAR spotlight mode SAR data.

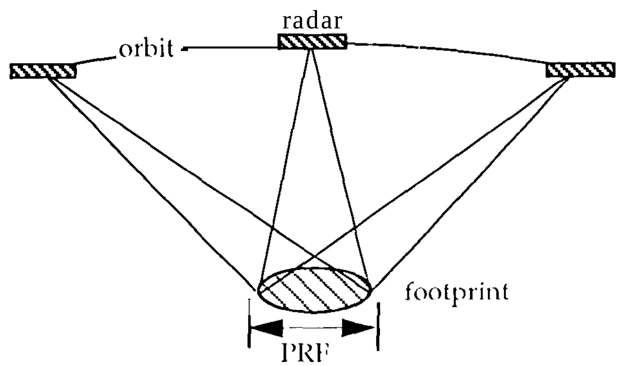

Figure 1. Spotlight Mode SAR Geometry

ALGORITHM

To generate a full resolution image from a conventional strip mode SAR data, the azimuth compression process may be realized in many ways. One simple approach is to perform a fast Fourier correlation type processing with a full length aperture. Typical example of this fast Fourier correlation include well known range-Doppler algorithm [4], wave domain algorithm [5], and the chirp scaling algorithm [6]. One may also perform fast Fourier correlation with sub apertures to generate several images with lower resolution. These images are then superposed to form a full resolution image provided that the azimuth sampling rate exceeds the Nyquist rate of the full resolution image. Or, one may merge the spectra of these subband images to form the full band spectrum and then take an inverse Fourier transform. Another approach is to divide the SAR data into a number of bursts, process each burst data into low resolution phase-preserved images, and superpose these images. It is interesting to point out that the backprojection algorithm may be viewed as an extreme case, i.e. one line per burst, of the burst processing approach.

In spotlight SAR data, the signal bandwidth is much greater than the pulse repetition rate (PRF). Consequently, full aperture processing by fast Fourier correlation is not possible because the PRF is less than the Nyquist rate of the full resolution image. Previously reported algorithms, other than the inverse Fourier from polar spectrum method, have proposed the backprojection algorithm [2] and the burst processing approache [3]. However, the subband processing approach was not explored at all. For an airborne SAR platform, the burst processing approach may be more adaptable to a system where motion compensation is required. But, in a spaceborne SAR, orbital trajectory is more stable and high frequency motion effect does not exist, the subband processing approach is, therefore, a very good candidate.

FORMULATION

In spotlight mode SAR operation, the radar pointing is constantly steered to keep the radar footprint illuminating a fixed spot on the ground during a time period several times longer than the conventional SAR aperture interval. This geometry is shown in Fig. 1. To simplify the illustration for the processing algorithm, it is assumed that the slant range history of each target within the radar footprint can remodeled by a polynomial limited to a second order. Therefore, the Doppler frequency profile associated with a point-like target within the radar footprint can be modeled as a ramp function with a negative slope. Since the along-track size of the processed spotlight image is limited to that equivalent to a Doppler range of PRF, the Doppler profile depicted in Fig. 2 may well characterize those targets within the final image and at a constant range to the radar.

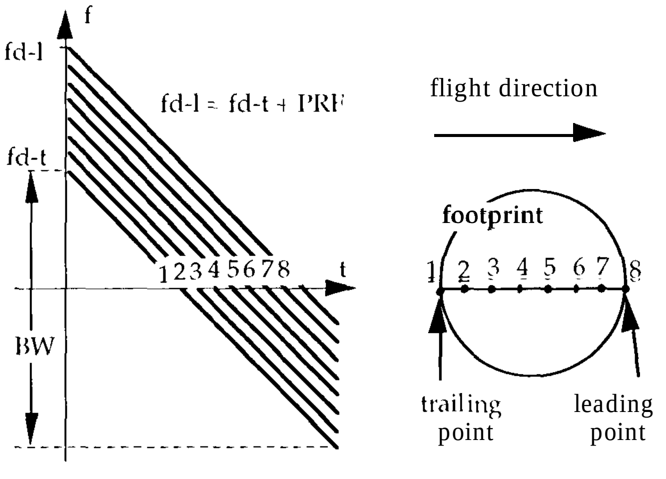

Figure 2. Targets Frequency Profiles

Frequency Interval in Subband Image

To apply a fast Fourier correlation to the spotlight data, the SAR data is divided into several segments first. Each segment data shall lead to a subband image of the illuminated ground spot. Let B_s be the bandwidth of each subband image satisfying $B_s \leq PRF$, $[0, T]$ be the time interval of the spotlight data. Denote f_{d-l} and f_{d-t} as the Doppler frequencies, at time origin, associated with the leading and trailing points, respectively, of the radar footprint. Let f_r be the Doppler frequency change rate. The first segment of the data should lead to an image covering the frequency interval of $[f_{d-l} - B_s, f_{d-l}]$. The i-th data segment should lead to an image covering $[f_{d-l} - i \cdot B_s, f_{d-l} - (i-1) \cdot B_s]$. Let the frequency bandwidth of each target be given by BW, the total number of segment N is given by the least integer satisfying $N \cdot B_s \geq BW + PRF$.

Time Interval in Subband Image

In fast Fourier correlation, the number of valid image samples is equal to the number of reference samples subtracted from the number of input samples. In a subband image processing, the number of valid image samples is given by the product of PRF and the equivalent time interval of the ground spot, $PRF / |f_r|$. The number of reference samples is given by $B_s / |f_r|$. Hence, the first data segment should contain the time interval of $[B_s/|f_r| - (B_s + PRF)/|f_r|, B_s/|f_r|]$. The i-th data segment should contain the time interval of $[i \cdot B_s/|f_r| - (B_s + PRF)/|f_r|, i \cdot B_s/|f_r|]$. The time and frequency intervals of these segments are shown in Fig. 3. The time intervals of burst processing approach is also given for comparison.

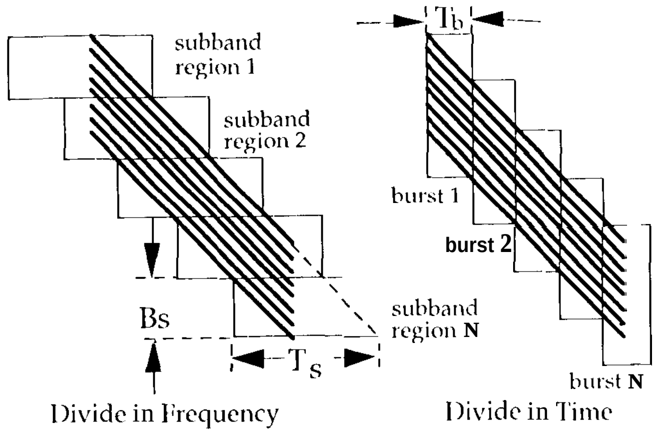

Figure 3. Subband and Burst Division

Spectra Merging

To merge the spectra from subband images into the full spectrum, one need to determine the sampling frequency of the final image. It should be no **less than** $T \cdot f_r$. To take the advantage of FFT, the sampling frequency must be the product of an integer power of two and PRF. Let a spectral component corresponding to a Doppler frequency of f_d. Its frequency value in the spectrum of the corresponding subband image is

$$f_{d-sub} = Mod[f_d + 100 \cdot PRF, PRF]$$

Its frequency value in the spectrum of the full resolution image is given by

$$f_{d-full} = Mod[f_d + 100 \cdot f_s, f_s]$$

SPOTLIGHT SAR DATA PROCESSING

The processing diagram of the proposed algorithm is given in Fig. 4. The radiometric compensation process is to remove the antenna pattern modulation and to eliminate the substandard image pixels near the edges of PRF boundary. This algorithm has been implemented in FORTRAN with both the range-Doppler and chirp scaling algorithms for subband processing.

This algorithm has been tested using both simulated spotlight point-target data and the spotlight data taken during the SIR-C mission. Analysis performed over the processed point-target data indicates that its Phase accuracy, 3-dB resolution width, peak-sidelobe ratio, and integrated-sidelobe ratio meet the LiteSAR requirement. Fig. 5 is a SIR-C spotlight SAR image, in full resolution and in multi-look lower resolution, of Sydney, Australia. By examining the point-targets performance in this and other image set, we conclude that the expected 1.25 meter full resolution is met.

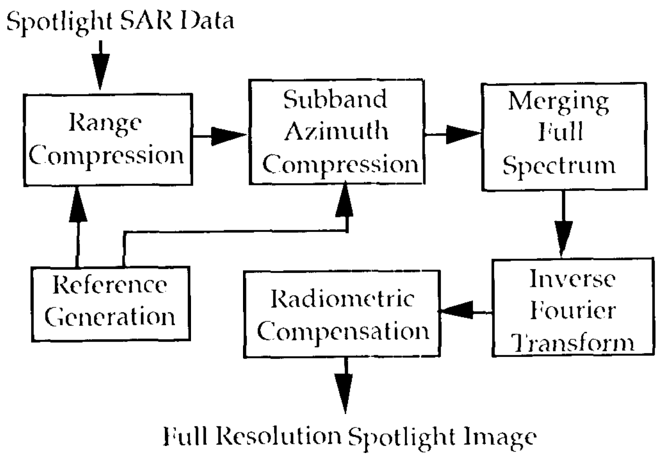

Figure 4. Spotlight SAR Data Processing Diagram

DISCUSSION

A squinted spotlight data may require a constantly changing PRF to let the echo fall between the transmitted pulses. To use the proposed algorithm for processing this kind data, resampling the raw data for a constant PRF is necessary. Depending on the bandwidth of the spotlight data, a 3rd and 4th order polynomial may be required for modeling the phase history accurately. Similar to a strip mode SAR processing system, an automated spotlight SAR processor ill also require pre'processing steps such as Doppler analysis and autofocus.

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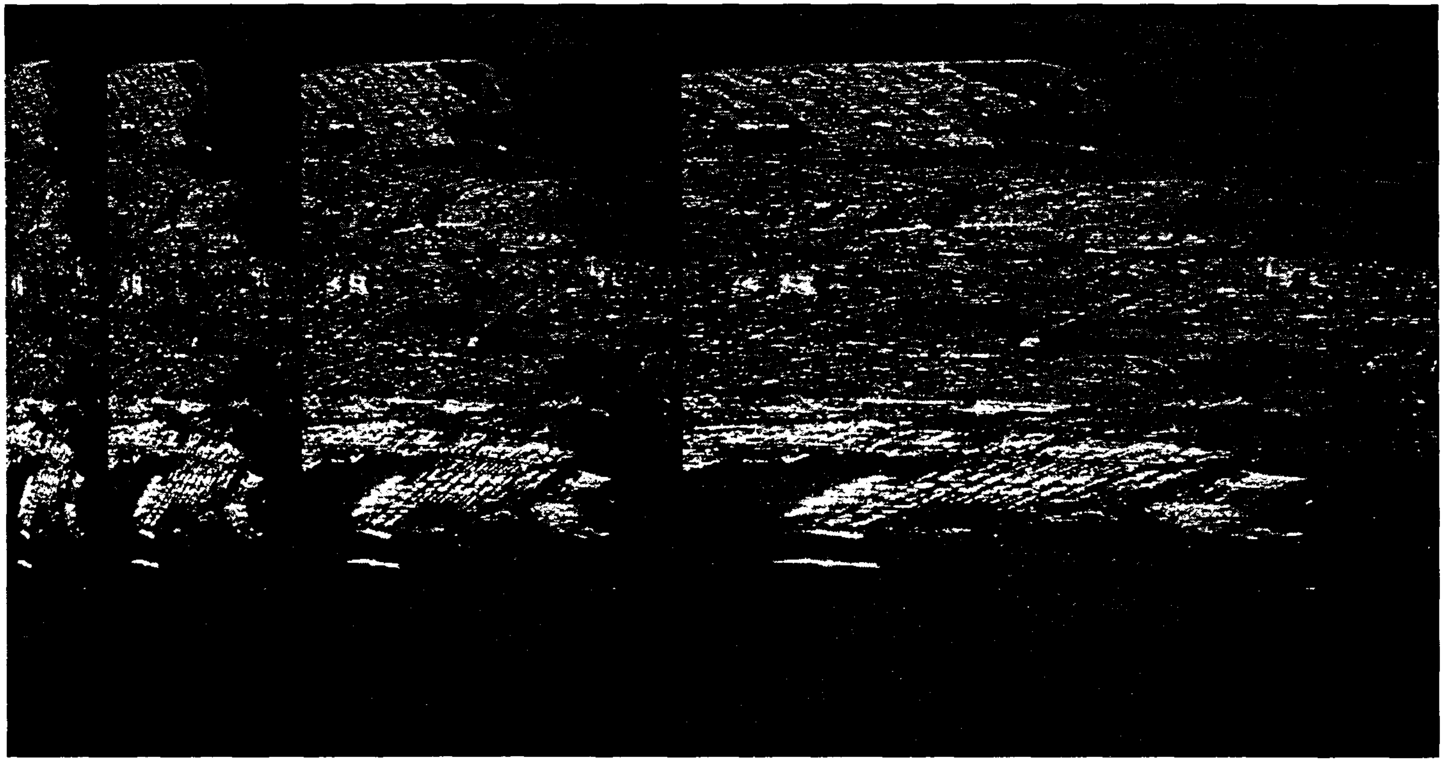
Site: Sydney, Australia
Image Size: 1.3 km along-track, 10 km cross-track
Look Angle: 42 degree

Range Resolution: 10 meter
Frequency: C band, Polarization: VV



Azimuth Resolution	10	5	2.5	1.25 (meter)
Looks	8	4	2	1

Figure 5. SIR-C Spotlight-Mode SAR Image