Modifying the RD Algorithm for Burst-Mode SAR Processing*

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ABSTRACT

In this paper, we investigate the applicability of the Short IFFT algorithm to burst-mode ScanSAR processing. We consider how the processed image data is connected at the burst boundaries, especially the phase properties. Finally, it is shown how the final image SNR is a function of the IFFT length.

1 Introduction

The Range/Doppler (RD) algorithm has long been a standard for processing conventional, continuous-mode SAR data. It combines computing efficiency with processing accuracy, and has been shown to have excellent phase properties for interferometric use.

Burst-mode data, such as obtained by RADARSAT and the future ENVISAT, has segmented frequency-time energy in its Doppler history. This requires special processing to maintain accurate focusing, consistent phase and efficient computing.

In applying the RD algorithm to burst-mode data, modifications can be made to:

1. preserve the conventional sin(x)/x form of the impulse response,
2. compensate for the phase properties of burst-mode data,
3. maintain high SNR, and
4. keep high computing efficiency.

We take the approach of modifying the inverse transform (IFFT) steps of azimuth compression to tailor the RD algorithm to burst-mode data. The key idea is to adjust the inverse transform length so that when one burst of a target is fully captured by the IFFT, little or no energy from adjacent bursts of the same target is present in the same IFFT. In this way, each IFFT compresses a group of targets without interference from other bursts, and an accurate impulse response is obtained. The IFFT is acting like a time-varying bandpass filter to extract target energy in the segmented form characteristic of burst-mode data. We have referred to this algorithm as the short IFFT or SIFFT algorithm [1].

In order to form a continuous output image, the results of successive IFFTs have to be stitched together. This happens in the RD algorithm applied to continuous-mode data, where a small amount of phased error occurs at the stitching points of the fast convolution blocks. This phase error originates from the time-domain tails of the circular frequency-domain matched filter, and can be controlled by a choice of weighting and IFFT throwaway regions. In the SIFFT algorithm, stitching occurs more often, and additional errors arise from the spreading of spectral energy in the burst operation. In this paper, we examine the form of phase discontinuity at the stitching points, and show how the SIFFT algorithm can be tuned to minimize it.

The segmented frequency-time history of burst-mode data means that targets are exposed for selected segments of Doppler energy. Each given target is exposed for a different

*Presented at the European Conference on Synthetic Aperture Radar, EUSAR'98, Friedrichshafen, Germany, May 25-27 1998.

portion of the Doppler spectrum. However, matched filters are usually applied for groups of targets at a time for efficiency reasons, with the result that the signal/noise ratio (SNR) of the compressed target is below its inherent value. We show how the SNR of targets can be improved in the SIFFT algorithm, so that an SNR/stitching error/efficiency tradeoff can be optimized for a given application.

2 The Short IFFT Algorithm

A typical ScanSAR data collection pattern is shown in Figure 1. The basic principle of the SIFFT algorithm is to take short IFFTs after the azimuth compression matched filter multiply in the range/Doppler domain. The rules for choosing the length and location of IFFTs can be deduced from Figure 2, where typical IFFT locations are shown along the bottom. It can be seen that IFFT 1 captures the complete energy of a single burst of Targets 1-5, 9-13 and 17-21.

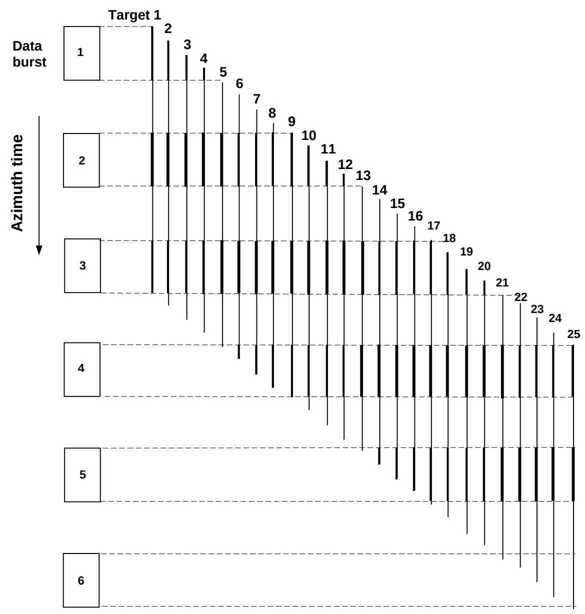

Figure 1: Illustrating the data collection pattern of 25 evenly-spaced targets.

As Target 5 is the last target of its group to be fully captured by IFFT 1, IFFT 2 should be placed so that Target 5 is the first of the next group of targets to be fully captured. From Figure 2, we can see how IFFT 2 captures Tar-

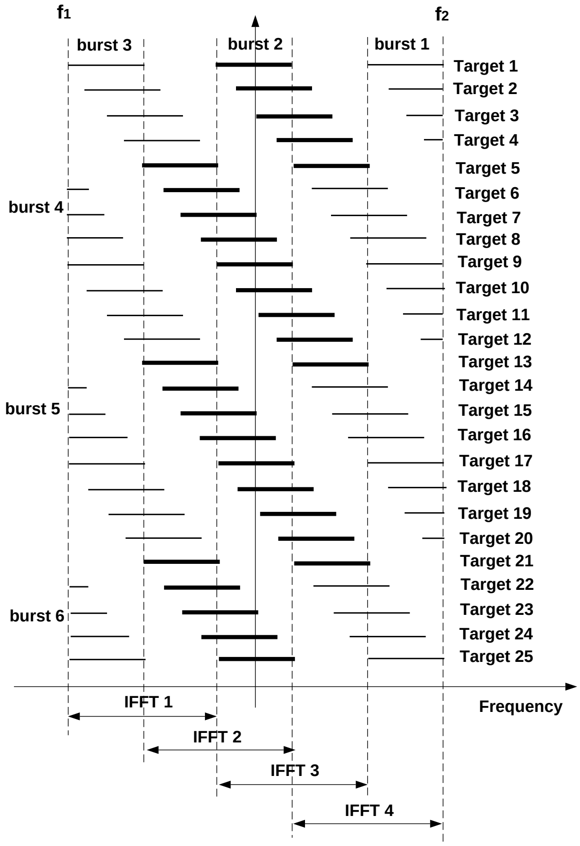

Figure 2: The Doppler frequency of each target in each burst.

gets 5-9, 13-17 and 21-25, so that contiguous output coverage is obtained. Similarly, IFFTs 3 and 4 are placed as shown in Figure 2, so that IFFTs 1-4 capture all the Doppler energy generated by the SAR beam during the time interval of the associated forward transform.

3 Stitching Output Points

In order to form a continuous output image, the results of successive IFFTs have to be stitched together. To illustrate the stitching operation, consider IFFTs 1 and 2 in Figure 2 where a 1280-point IFFT is taken. The outputs of these IFFTs are shown in the top two panels of Figure 3, where the first 600 output points of the IFFT are shown. It is noted that Targets 1-5 and 9-10 are cleanly compressed in IFFT 1, whereas Targets 6-8 are not. The reason for this is apparent in Figure 2, where Targets 1-5 and 9-10 are fully exposed in contiguous samples of the domain of IFFT 1, whereas the exposure of Targets 6-8 is disjoint.

Looking at the IFFT 2 output, it is seen that the targets which were corrupted in IFFT 1 are now compressed correctly, while those compressed correctly in IFFT 1 are now corrupted. Examining this pattern of fully and partially compressed targets, it is evident how to combine the outputs of IFFT 1 and IFFT 2 to form a contiguous set of well-compressed targets in the output array. This combined or stitched output is illustrated in the bottom panel of Figure 3.

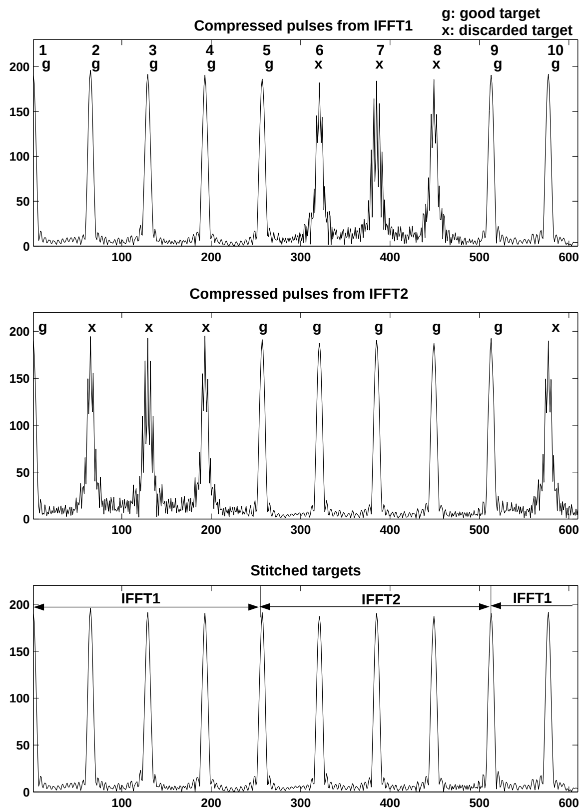

Figure 3: Stitching together groups of SIFFT output points.

3.1 Phase Errors Due to Stitching

Two stitches can be seen in Figure 3. At Target 5, a simple stitch is made across the two IFFTs, but taken from within the same burst. This stitch was found to suffer only a minor phase error[1] of a few degrees, the same that happens in the stitches of the continuous-mode RD algorithm.

However, the stitch at Target 9 joins targets together which are taken from different bursts. The response of this target sitting on the stitching boundary is shown in Figure 4. Note that the magnitude response suffers a small amount of distortion, but is a well-structured response with a resolution of 2.32 samples.

Somewhat more distortion is noted in the *phase* of Figure 4. The samples to the left of sample zero come from IFFT 2, where the target is captured in Burst 3. This exposure of Target 9 has a near-zero Doppler centroid, resulting in a flat phase response. On the right side of sample zero, the output comes from IFFT 1 where the energy of Targets 9-13 is extracted from burst 4. Targets from IFFT 1 have a negative Doppler centroid, giving rise to the steep phase modulation noticed in the right-hand side of the phase curve. Even though the peak phase is close to being correct at 1.9^o, the average phase is distorted by the stitching.

As the target can occur at an arbitrary inter-sample position, it is useful to look at the average phase error as the target takes on various positions with respect to the stitching point. Figure 5 gives the impulse response when the target is one sample (0.5 resolution cells) away from the stitch, and Figure 6 gives the average phase error when the target position varies from -2.5 to +2.5 samples from the stitching point. The phase error peaks at the stitching point and decreases linearly to zero two samples away from the stitching point.

These figures represent a worst case, because a large inter-burst Doppler discontinuity was used. If the inter-burst frequency step is close to the output sampling rate after the IFFT, favourable aliasing will substantially reduce the phase error. In other words, this phase error can be controlled by suitable choice of the IFFT length.

[1]The phase error is quantified by its average value across the main lobe of the impulse response.

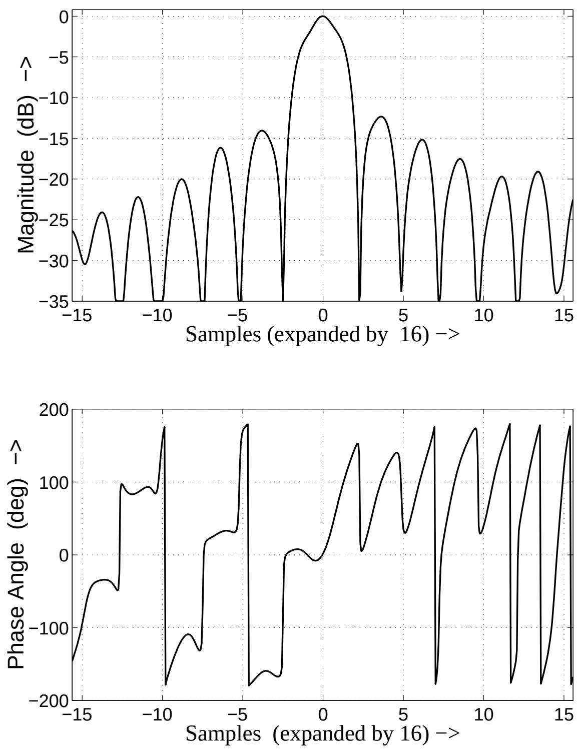

Figure 4: Response when cross-burst stitch occurs at target peak (Target 9).

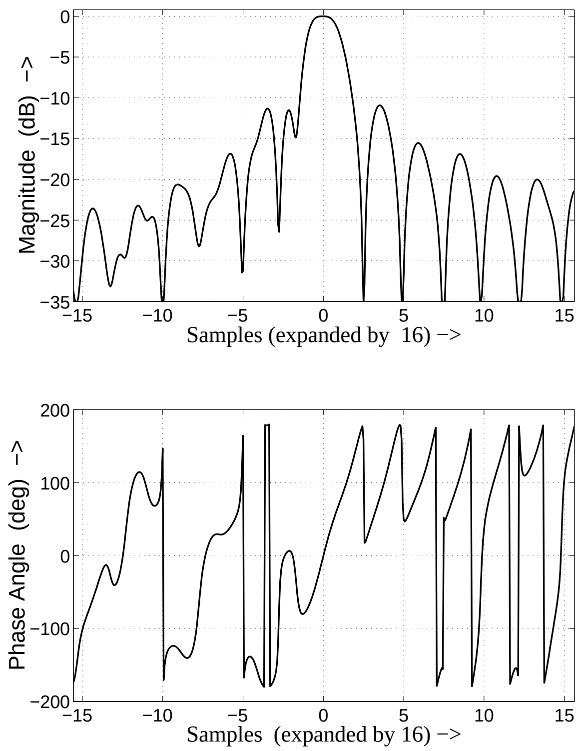

Figure 5: Response when cross-burst stitch occurs one sample off target peak.

4 Signal/Noise Ratios

In the SIFFT algorithm, we have chosen IFFT lengths which compress more than one target at a time in order to improve their efficiency. However, these wider matched filters extract more noise energy, which lowers the SNR of the compressed data. For example, as the IFFT length is doubled, 3 dB more noise is extracted from the Doppler energy.

To illustrate this effect, and to compare it with the ideal result, noise was included in the earlier simulations. Runs were done with IFFT lengths from 600 to 1000 in steps of 50, and the resulting SNR plotted in Figure 7. The results follow the expected 3 dB/octave slope to within the accuracy of the measurements (about ± 0.5 dB). The SNR of the ideal case is also shown, and corresponds approximately to the SNR of the shortest possible IFFT.

Thus when longer IFFTs are used to gain efficiency, SNR suffers. In addition, longer IFFTs result in a larger oversampling ratio at the output, which is usually not desirable. In reference [2], we show how the IFFT length can be easily changed to obtain the best SNR/stitching error/efficiency tradeoff for a given application.

5 Conclusions

We have extended the study of the SIFFT algorithm to look at the stitching error across the stitching points, and the effect of IFFT length on the compressed signal/noise ratio. The stitching error can be controlled by suitable choice of IFFT length, the SNR is improved by using shorter IFFT lengths, while the efficiency is improved with longer IFFT lengths.

Acknowledgements

The authors would like to thank the Canadian Natural Sciences and Engineering Research Council (NSERC), and MacDonald Dettwiler

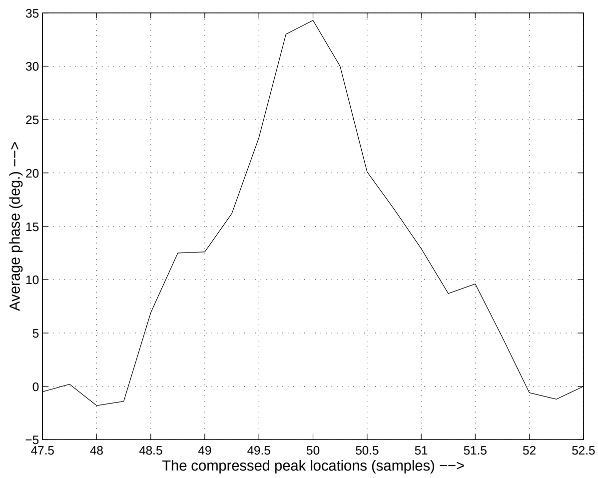

Figure 6: Average phase error when target is near the stitching point.

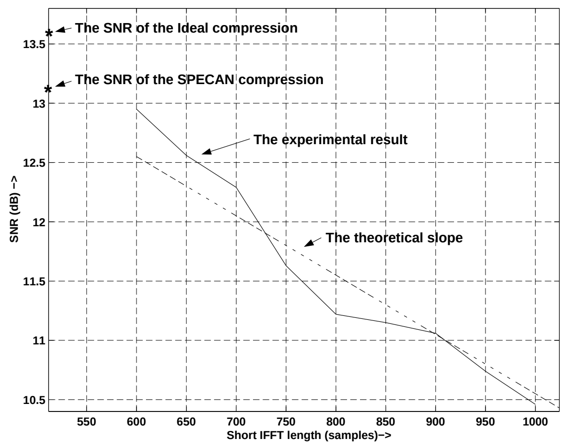

Figure 7: Effect of IFFT length on SNR.

(MDA) for major funding of this research.

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[2] Sandor Albrecht and Ian Cumming. Application of the Momentary Fourier Transform to SIFFT SAR Processing. In *Proceedings of the IEEE-SP International Symposium on Time-Frequency and Time-Scale Analysis*, Pittsburgh, USA, October 7–9, 1998.