Memorandum

From: Clint Slatton
To: Prof. Brian Evans
Subject: Term project idea for Multidimensional Signal Processing (EE381k)
Date: 16-Sep-98

Project title: Minimizing segmentation discontinuities in the topographic height measurements derived from interferometric synthetic aperture radar (INSAR) data

Background

Imaging radars comprise an important class of sensors for remote sensing and military reconnaissance applications because they access the microwave portion of the spectrum and are capable of day/night, and nearly all-weather operation. Raw data from imaging radars consist of successive time histories of scattered frequency-modulated pulses as the sensor moves past a target (see Figure 1). In the general case, these data form a non-separable 2D process [1]. However, they are typically approximated as two separable 1D processes. Data from each radar pulse is correlated with the transmitted chirp waveform (match filtered) in an operation called range compression. Then the range-compressed data must be correlated in the azimuth direction (azimuth compression) [2]. Because the velocity of the platform is small compared with the velocity of the EM wave front, the approximation that the correlation of a returned pulse is independent of the correlation of adjacent pulse histories (after a range migration correction is applied) typically leads to acceptably small errors. This approach to synthetic aperture radar (SAR) processing is the most common and is called Range-Doppler processing.

Modern fully-polarimetric, dual-antenna SAR systems require extremely high data rates. Therefore it is common practice to process data from a single flight line in segments (also referred to as patches) to limit the size of the arrays that must be stored during processing. In the case of airborne platforms, attitude and position of the sensor vary throughout the flight line in a non-deterministic manner. To create an internally consistent SAR image, the processor must compensate for these deviations from the nominal trajectory, which result in variations in beam direction (squinting). The motion compensation and squint parameters will be different from patch to patch [3] [4] [5].

The problem

While well-known de-skew [2] processing is typically sufficient to remove patch-to-patch artifacts in the intensity images, it is insufficient for removing artifacts in the interferometric phase images. This is because at typical wavelengths of 5 cm (C-band), the phase measurement is very sensitive to incorrectly compensated motion. Figure 2 shows an intensity image acquired from the NASA/JPL TOPSAR aircraft. Figure 3 shows the topographic height map (generated from unwrapping the interferometric phase) over the same area. The discontinuities among patches are roughly 2 m in magnitude, which are unacceptable for measuring topography in low-relief coastal regions.

An image of topographic heights is shown in Figure 3. Careful examination of Figure 3 shows that the corruption is not simply a 1D process. The sharp discontinuity is a function only of the azimuth coordinate, but the height variations on either side of a boundary are functions of both range and azimuth coordinates. Each patch is not only offset vertically from its neighbor but is tilted relative to it. Also, the discontinuity decreases with increasing range. Even if we assume separability by using Range-Doppler processing, we still have a 2D error. We want to retain the Range-Doppler approach to processing since it is so common, but we propose to reduce these artifacts to realize the full potential of INSAR to map topography.

The proposed solution

The NASA/JPL TOPSAR processor is the most advanced fully-polarimetric, interferometric SAR processor currently in operation. However, it does exhibit patch boundary artifacts, and there are two operations that could be improved or introduced into the processing to ameliorate these artifacts. Existing motion compensation in the TOPSAR processor might be improved, and the data from the two TOPSAR antennas might be regularized. Regularization of the two data channels is basically a resampling operation. The data are upsampled and then downsampled to a desired spacing in a technique known as pre-summing [6] [7]. I will investigate only the pre-summing issue for this project. A pre-summing algorithm will be developed as a pre-processing operation for the TOPSAR processor. Data processed with the pre-summing will be compared to data that has not been pre-summed, and improvements in the data quality will be assessed. See Appendix 1 for a detailed research plan.

References

[1] R. Bamler, "A Comparison of Range-Doppler and Wavenumber Domain SAR Focusing Algorithms," *IEEE Trans. on Geoscience and Remote Sensing*, July 1992, vol. 30, no. 4, pp. 706-713.

[2] J. C. Curlander and R. N. McDonough, *Synthetic Aperture Radar: Systems and Signal Processing*, John Wiley & Sons, ISBN 0-471-85770-X, 1991.

[3] J. J. Van Zyl, A. Chu, S. Hensley, Y. Lou, Y. Kim, and S. N. Madsen, "Integrated Multi-Frequency Polarimetric and Interferometric SAR Processing Techniques," *IEEE Trans. on Geoscience and Remote Sensing*, 1998, submitted.

[4] E. Chapin, S. Hensley, A. Safaeinili, and E. Rodriguez, "Calibration of TOPSAR Cross-Track Interferometric Data Processed With the IFPROC Processor," *JPL Airborne Science Workshop*, May 1998, vol. 2, pp. 13-18.

[5] D. R. Stevens, I. G. Cumming, and A. L. Gray, "Options for Airborne Interferometric SAR Motion Compensation," *IEEE Trans. on Geoscience and Remote Sensing*, March 1995, vol. 33, no. 2, pp. 409-420.

[6] J. J. Kovaly (ed.), *Synthetic Aperture Radar*, Artech, ISBN 0-89006-056-8, 1976, pp. 72, 118, 249-259.

[7] P. Rosen, "Pre-Azimuth Compression Decimation (Pre-summing) Filters and Azimuth Ambiguities," JPL internal memorandum, December 30, 1992.

Figures

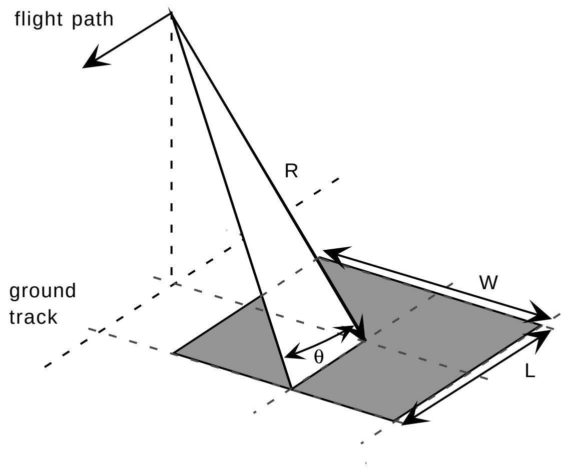

Figure 1-A. Geometry for an imaging radar including Doppler dependency [Kovaly, pp. 118]. L = length of the synthetic aperture (approximate horizontal beam width), W = swath width, θ = angle that determines the Doppler frequency.

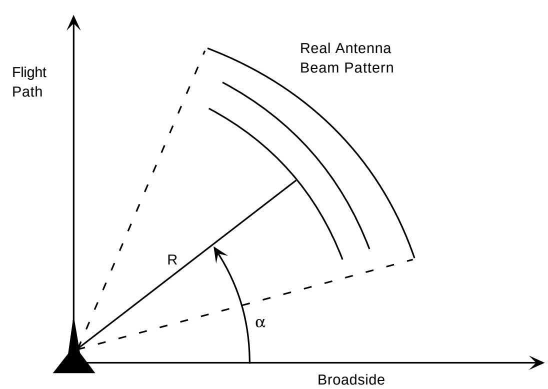

Figure 1-B. Top-view of imaging geometry showing a squinted beam [Kovaly, pp. 72]. α = squint angle.

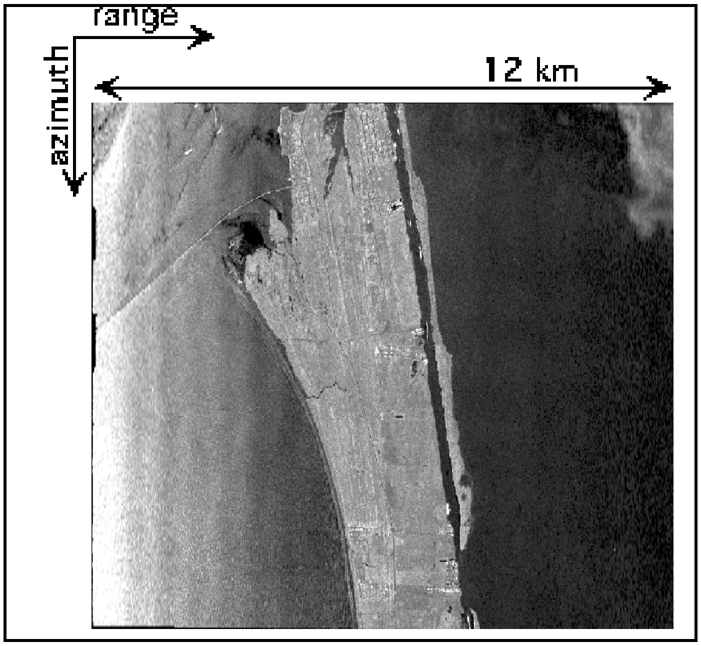

Figure 2. Intensity image of Bolivar Peninsula, Texas, USA acquired by the TOPSAR sensor. Pixel values correspond to backscattering coefficient σ^0, where λ=5.6 cm, transmit/receive polarization = vv)

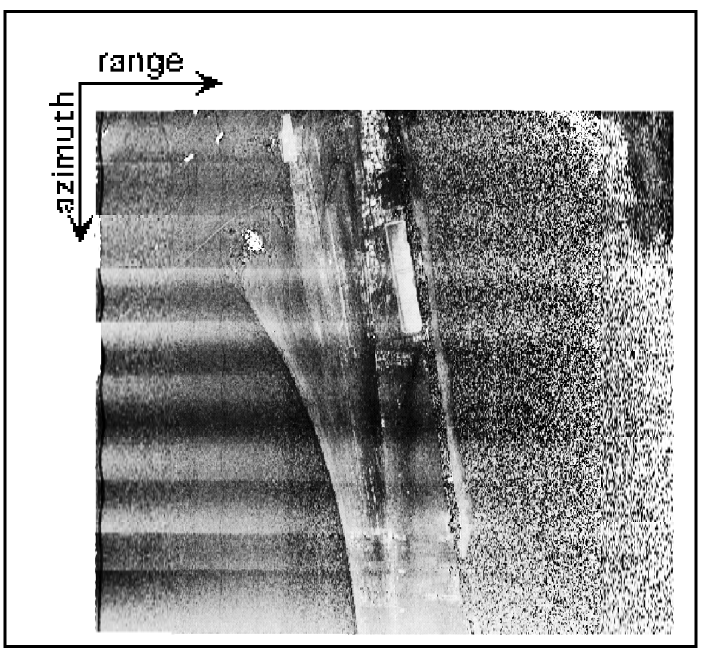

Figure 3. Topographic height image of Bolivar Peninsula, Texas, USA

Appendix 1

Research plan:

(1) Study basic theory of SAR imaging and interferometric SAR measurements

(2) Study recent papers on pre-summing

(3) Implement pre-summing for the TOPSAR processor

(4) Asses the improvement in data quality relative to non-pre-summed data