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HIGH RESOLUTION TERRAIN ELEVATION MAPPING RESULTS FROM AIRBORNE CROSS-TRACK SAR STEREO

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Abstract

In this paper we demonstrate that a unique mode of spotlight-mode synthetic aperture radar collection known as "cross-track stereo" can be employed to produce high-resolution three-dimensional maps of the earth surface. This mode is especially effective for two reasons. First, the illumination direction is identical for the two images of the pair. Second, the stereo correlation calculation can be performed on complex image data instead of magnitude-only data, because the two images of the stereo pair are in fact coherent. We review the mathematics of cross-track stereo, and then demonstrate with actual SAR imagery the ability to create 3-D images with height resolution that is on the order of several inches when computed on 1-foot by 1-foot postings.

1 Introduction

Several traditional modes of computing three-dimensional maps of the earth surface from stereoscopic pairs of spotlight-mode SAR imagery have been described in the literature [1]. There is another mode for collection and processing of spotlight SAR stereoscopic data that turns out to be far more useful than any of the ones considered in [1], however. We introduced this other mode in 1997 and dubbed it "cross-track stereo". Its collection geometry is shown in Figure 1. The advantage of cross-track stereo is that the two images collected can be made to be spatially coherent, by choosing the synthetic aperture centers to be nearly identical. This collection methodology results in two distinct advantages. First, the two images are illuminated from the same direction, so that all of the macroscopic properties of the microwave reflectivity (e.g., shadows) are essentially the same in both. Second, the image-domain correlations that are required to compute the stereoscopic height map can then be performed with the complex image data, as opposed to magnitude-only data. This effectively means that the speckle patterns in the images are the same. These effects result in a more robust estimation of the stereo lags ("parallax") and a higher fidelity map than can typically be produced by the traditional SAR stereo modes.

2 Review of Cross-Track SAR Stereo

As indicated in Figure 1, the projection (layover)of targets onto the two-dimensional spotlight-mode SAR images in a cross-track stereo pair is such that the range component of layover is common to both and is given by $h \tan \psi$, where ψ is the depression angle for the center pulse, common to both of the synthetic apertures. The cross-range component, on the other hand, is equal in magnitude but opposite in direction for the image pair, and is given by $h \tan \psi \tan \theta_g$, with $\tan \theta_g$ the ground-plane squint angle (see Figure 1). As a result, the differential layover (parallax) between the two images is purely in the cross-range dimension. (An equivalent statement is that the so-called "epipolar direction" [4] is the cross-range direction.) The differential layover is given by:

$$\delta x = 2h \tan \psi \tan \theta_g \tag{1}$$

The stereo map is computed by correlating (in the cross-range dimension) an N-pixel wide chip from the first image with the second. Location of the peak of the correlation function then yields the estimate for the cross-range parallax, from which the height for that posting is inferred from Equation 1.

3 Results from High-Resolution Airborne Spotlight-Mode Cross-Track Collections

We flew the Sandia National Labs Twin Otter 16GHz SAR in a cross-track stereo mode against a scene on Kirtland AFB, NM. A pair of spotlight-mode images formed at 4-inch spatial resolution in both range and cross-range is shown at the top of Figure 2. The bottom image in Figure 2 shows the computed stereoscopic elevation map, with height encoded as intensity. The map is computed on 1-foot by 1-foot postings, which are obtained from correlating with 3x3 boxes of the 4-inch resolution image pixels. The tops of the one-story buildings appear to be relatively smooth as expected, because they are of flat-roof construction. Note also that the road and grass areas appear to have constant elevation. We measured

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the smoothness of these rooftop, grass, and road areas as a quantitative measure of the accuracy of the stereo technique. The following results were obtained for RMS variation across these areas: Road 4 in Roof 2 in Grass 2.5 in As for the trees in the scene, the correlation of the complex image data generally fails completely, yielding no useable stereo height data, because the leaves of the trees can move by substantial fractions of a wavelength between the first and second image collections. In this case, it is necessary to use only the image magnitude data for the stereo correlations. Note that in the height map of Figure 2 that the trees appear to be tracked fairly well by the correlator, as they clearly have calculated elevations that are greater than the building roofs, as they should.

4 Conclusions

Pairs of high-resolution spotlight-mode images collected in a cross-track stereo mode can result in computed stereo elevation maps of remarkable accuracy. We have demonstrated here that starting with 4-inch spatial resolution imagery, digital stereo elevation maps can be created with RMS height accuracies (relative) of only a few inches, computed on 1-foot by 1-foot post spacings. This mode of stereo appears to be superior to traditional stereo collection modalities, because the two images of the pair are not only illuminated form the same direction, but also can be made to be spatially coherent, allowing for the stereo correspondence (correlation) calculations to be performed with the complex image data, instead of only the magnitude data. When trees are involved in the scene, however, use of the complex images may not be appropriate, due to temporal decorrelation of the complex image data. In these cases, the magnitude data are employed, and tree heights can be successfully calculated.

5 Acknowledgments

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6 References

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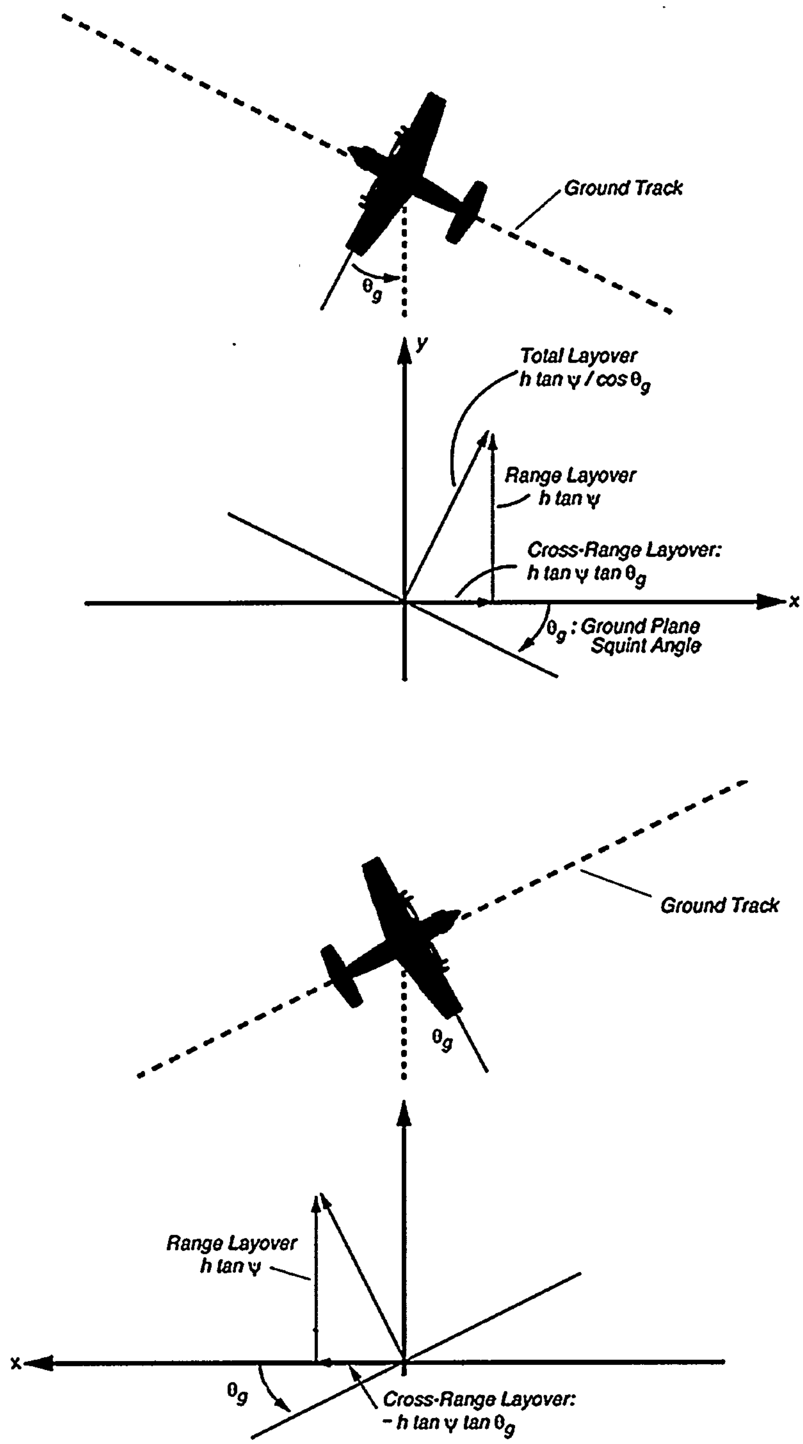

Figure 1: Geometry for cross-track stereo collection

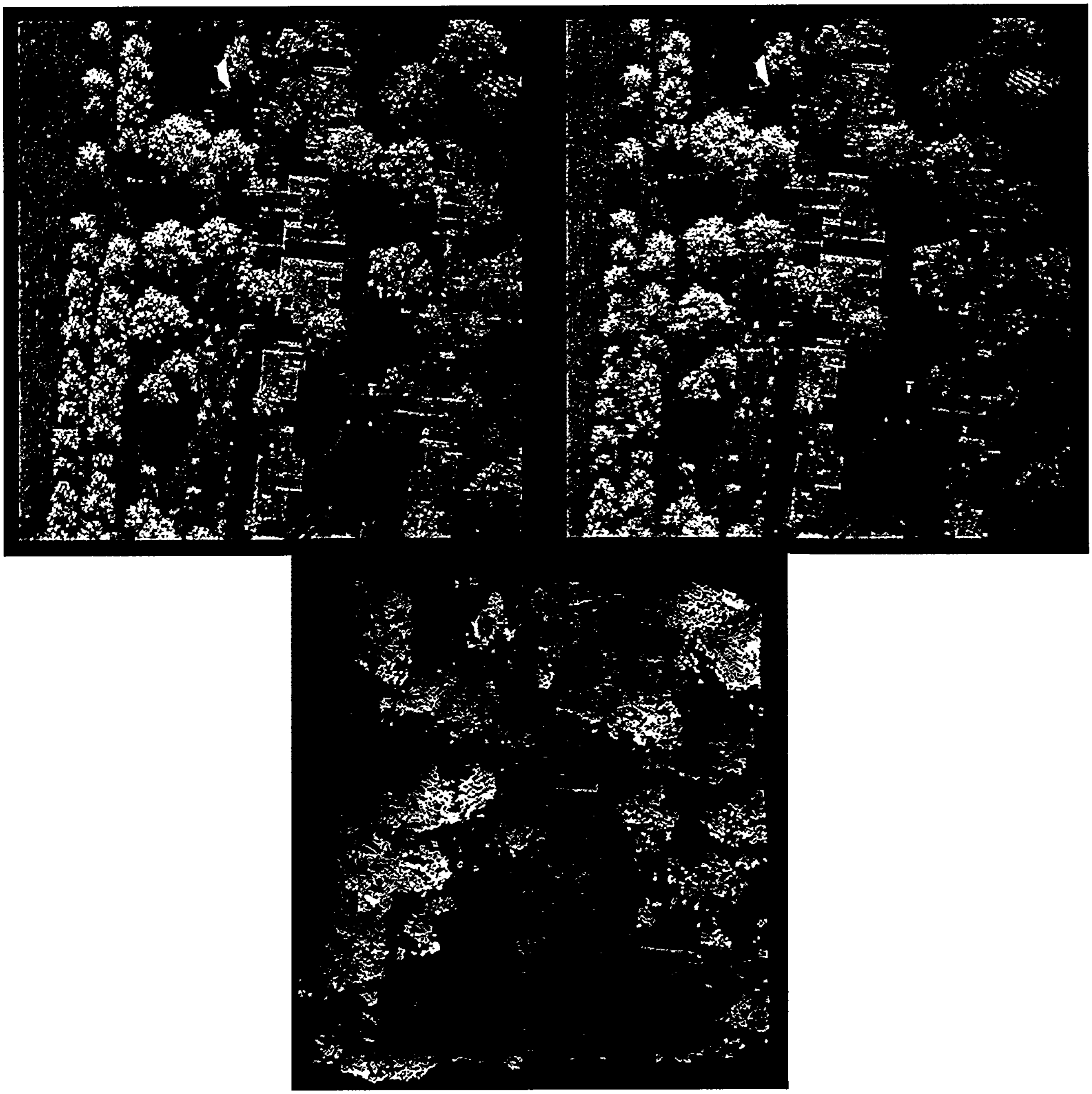

Figure 2: Top: Pair of SAR images used for stereo processing. Resolution is 4 inches in range and cross-range; Bottom: Height map derived from cross-track stereo algorithm. Elevations are computed on 1-foot post spacing. Estimated RMS height error is approx. 6 inches.