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Three-Dimensional SAR Imaging Using Cross-Track Coherent Stereo Collections

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Abstract

In this paper we describe a new method for creating three-dimensional images using pairs of synthetic aperture radar (SAR) images obtained from a unique collection geometry. This collection mode involves synthetic apertures that have a common center. In this sense the illumination directions for the two SAR images are the same, while the slant planes are at different spatial orientations. The slant plane orientations give rise to cross-range layover (foreshortening) components in the two images that are of equal magnitude but opposite directions. This differential cross-range layover is therefore proportional to the elevation of a given target, which is completely analogous to the situation in stereo optical imaging, wherein two film planes (corresponding to the two slant planes) result in elevation-dependent parallax. Because the two SAR collections are coherent in this particular collection mode, the images have the same speckle patterns throughout. As a result, the images may be placed into stereo correspondence via calculation of correlations between micro-patches of the complex image data. The resulting computed digital stereo elevation map can be quite accurate. Alternatively, an analog anaglyph can be displayed for 3-D viewing, avoiding the necessity of the stereo correspondence calculation.

1. Introduction

Determination of terrain elevation from SAR images collected in stereoscopic pairs relies upon *differential layover* in the two SAR scenes. The layover (or foreshortening) effect in a SAR image is a function of the orientation of the SAR slant plane, and is a *projection effect*, completely analogous to the projection of elevated targets in a direction normal to the film plane in optical imaging. In spotlight-mode SAR imaging, the projection of elevated targets is *always in a direction normal to the slant plane*. For imagery

formed in the so-called *ground plane*, the elevated target's position in the image is at the intersection of this projection vector and the ground plane. As a result, the direction of the layover in the ground plane image will be *normal to the line of intersection of the ground plane and the slant plane*. For the case of level flight of the aircraft, this implies that the layover direction is *normal to the line of the aircraft ground track*. Figure 1 shows the projection effect in ground plane spotlight-mode SAR imagery for the case of a level-flight broadside collection (illumination direction orthogonal to the flight path). Because the aircraft ground track in this situation is a line orthogonal to the range dimension in the image, the layover has only a range component. As a result, this situation has traditionally been referred to as *range layover*. Figure 2 depicts a somewhat more complicated situation wherein the direction of illumination is *not* orthogonal to the flight path. This collection geometry is known as *squint mode*. Here, the projection of elevated targets in a direction normal to the slant plane results in layover in the ground plane image that has both range and cross-range components. Figure 3 shows what these layover components are, expressed in terms of the depression angle, ψ , the ground-plane squint angle, θ_g , and the elevation of the target, h . As a check, note that for the special case of $\theta_g = 0$, corresponding to a broadside collection, the cross-range component of layover becomes zero, and we are left with the situation of range-only layover.

2. Determination of Scene Elevation by Stereo Processing of Cross-Track Coherent SAR Collections

Figures 4 and 5 depict a scenario for which the layover geometry for a pair of squinted spotlight-mode images may be exploited in a novel stereoscopic mode for three-dimensional imaging. The aircraft flight paths for the two collections cross, such that the two synthetic apertures are both centered at the crossing point. The im-

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ages are both squinted, one forward and the other back, by the same ground-plane squint angle, θ_g , while the depression angles are the same and given by ψ . (Since the flight paths are level, the aircraft headings are also equal to $\pm\theta_g$.) From the discussion above and reference to Figure 3, it is clear that any elevated target of height h in this pair of images will have the same range component of layover, given by $h \tan \psi$, while the cross-range layover components are in opposite directions, but have the same magnitude of $h \tan \psi \tan \theta_g$. As a result, the height of any target in the scene may be calculated by locating the target in both images, determining the amount of cross-range differential layover, and scaling the layover to height by the factor $\tan \psi \tan \theta_g$.

3. Results of Stereo Elevation Calculation Using Real SAR Imagery

We obtained coherent SAR stereo image pairs corresponding to the geometry described above. These data were collected by the Sandia National Laboratories Twin Otter airborne SAR, operating at 15 GHz center frequency, with resolution of 1 foot in both the range and cross-range dimensions. The crossing angle for the collections was 20 degrees, while the depression angle employed for both images was 35 degrees. Figure 6 shows the pair of detected images. Each ground-plane image covers approximately 400 meters on a side. In this case, the scene is one of storage bunkers on Kirtland AFB in New Mexico. Figure 7 shows a computer rendering of the height map that was calculated according to the coherent cross-track stereo technique described above. Neighborhoods of 7×7 pixels were employed in the stereo correspondence algorithm, so that the resulting computed topological map is on postings of approximately 5×5 feet (the image data are of 1 foot resolution, but are oversampled.) In this case, the calculated terrain elevations are accurate to approximately 1 foot rms. The bunkers, which are roughly 12 feet tall, can clearly be seen in the displayed height map. Note also that a chain link fence is clearly seen in this rendering. Finally, we comment on the importance of the image pair being collected in this coherent mode, i.e., the center point of the two synthetic apertures is coincident. This implies that the speckle patterns of the two images are essentially identical throughout the imagery, so that the stereo correspondence algorithm can "lock up" on this high-spatial-frequency information.

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5. References

- [1] Charles V. Jakowatz, Jr., et. al., **Spotlight-Mode Synthetic Aperture Radar: A Signal Processing Approach**, Kluwer Academic Publishers, Boston, 1996.

Figure 1. Layover geometry in a broadside collection.

Figure 2. Layover geometry in a squinted collection.

Figure 3. Components of layover in ground-plane squinted image.

Figure 4. Layover geometry in a broadside collection.

Figure 5. Layover geometry in a broadside collection.

Figure 6. Pair of SAR images collected in coherent stereo mode.

Figure 7. Rendering of computed stereoscopic elevations using coherent stereo pair.