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The Effect of Scattering from Buildings on Interferometric SAR Measurements

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Abstract

The determination of elevation models of buildings using interferometric synthetic aperture radar (IFSAR) is an important area of active research. The focus of this paper is on some of the unique scattering mechanisms that occur with buildings and how they affect the IFSAR height measurement and the coherence. We will show by theory and examples that the various data products obtained from IFSAR can be used to aid in interpreting building height results. We will also present a method that we have used successfully in mapping buildings in Washington D. C.

Introduction

IFSAR has become an important technology in providing digital elevation models (DEMs). Some advantages of IFSAR include all-weather capability and the promise of rapid-turnaround products by automated techniques. The latter is particularly important in the areas with buildings and other man-made structures.

Urban areas and other areas with buildings present great challenges for IFSAR processing. These challenges include height discontinuities, a large dynamic range of the image, layover, shadowing, multipath reflections, multiplicative noise from sidelobes, areas of low coherence, and so on. Natural terrain can exhibit these problems as well, but they are typically not as severe nor as prevalent as in urban areas.

Another issue is that the buildings can be relatively small, and thus require fine resolution. Finer resolution leads to image processing and signal-to-noise ratio (SNR) issues.

In the following sections, we will briefly touch on some of the problems presented above. In most of this paper, we will focus on the challenges presented by layover, and the role that the coherence plays in this area.

Scattering Example

Figure 1, an example image of the U. S. Capitol building, to illustrates some of the scattering issues encountered in SAR images of buildings. The large dynamic range is apparent in the image. The building is dominated by areas of very bright isolated targets in close proximity to areas of no return. For IFSAR this implies that the multilook operation results in using pixels whose contribution is predominantly noise. Ideally, the multilook window size could be reduced for areas of high SNR.

Layover is an obvious problem in this image. The intense returns from the dome layover on top of the steps of the Capitol building. This makes retrieval of the height information from the steps very difficult. What may be less apparent is that the return from the steps can distort the height information of the dome. This issue, previously referred to as the “front-porch” effect in [1], will be discussed more later.

Many examples of shadowing are obvious in Figure 1. Less obvious is the presence of multipath near the edges of the building and around the dome and rotunda.

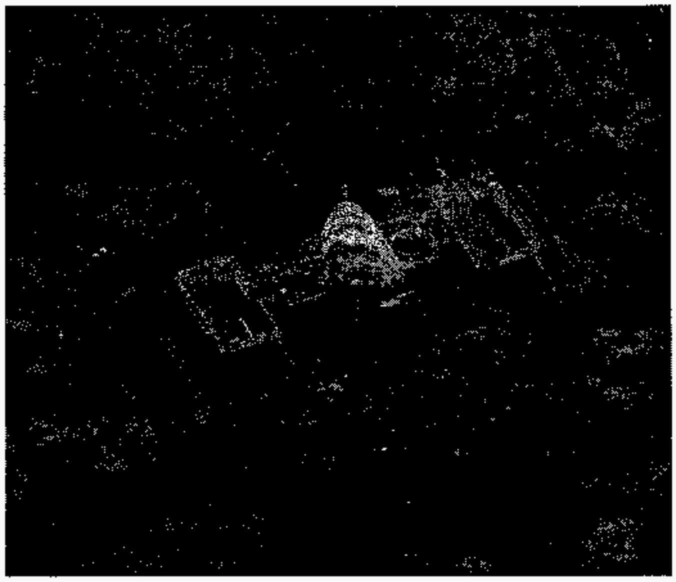

Figure 1: Example Image of the U. S. Capitol from the SNL Twin-Otter IFSAR Platform (near-range at top of image)

DISCLAIMER

Issues in Reprojection for Orthorectification

The geometry of the measurements of IFSAR are in a (slant) range-Doppler plane projection. Typically, the results of the IFSAR measurements are reprojected into a top-down-looking geometry. A problem is presented in the reprojection, because the slant range may contain several samples from different parts of the side of the building located at several different heights. Figure 2 illustrates this problem. For the building, several heights are appropriate for the side of the building, ranging from the ground to the top of the building. The question becomes, which height is the appropriate height to use in the DEM? For terrain, we have chosen the height that corresponds to the maximum coherence [1]. For buildings, the DEMs are more presentable if they use the top of the building. Very often in buildings the height that corresponds to the maximum coherence does not correspond to the top of the building. In fact, the opposite is often true, due to the common presence of the strong dihedral return off of the front of the buildings. To find the top of the building, we must choose the maximum height given a reasonable coherence function. This idea can be thought of as an extension of the famous Golden Gate bridge example in [2].

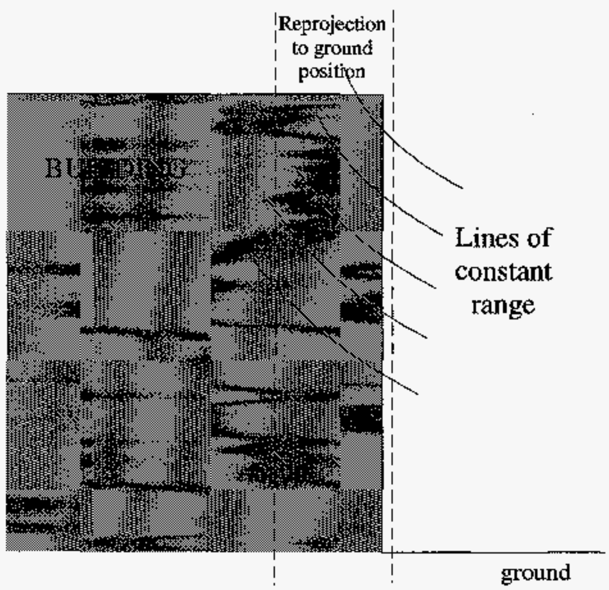

Figure 2: Multiple samples of side of building

Coherence and Layover of Buildings

IFSAR systems are built with the assumption that there is only one height sample per range-Doppler bin. In the case of layover, this assumption is invalid. In Figure 3, the front of the building is illustrated with the typical two competing samples at the top and the bottom of the building. As will be shown, the height determined by the IFSAR can be anywhere from the top to the bottom of the building, within the range shell shown in the figure. The location within the range shell is determined by the ratio of the return from the top of the building to that of the bottom of the building. If the backscatter coefficients for the top and the bottom of the building are similar, the result is that the front edge of a building is shortened and pulled forward creating a false "front-porch" on the building.

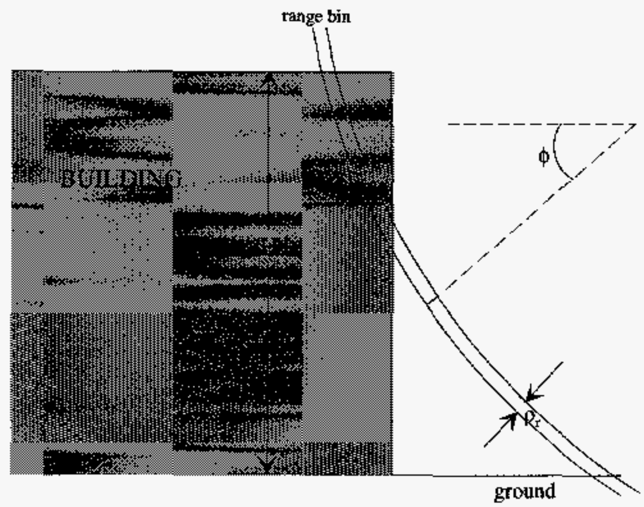

Figure 3: The effect of layover on IFSAR

The effects of layover in terms of estimated height as well as coherence can be explained by the van Cittert-Zernike theorem [3], [4]. In the case where several simplifying assumptions have been made, the normalized complex coherence can be shown to be:

$$\mu \approx \frac{\sin(\pi \cdot X)}{\pi \cdot X} \cdot \left\{ \beta \cdot \exp\left[\alpha \cdot \left(\frac{H}{2} \right) \right] + (1-\beta) \cdot \exp\left[\alpha \cdot \left(-\frac{H}{2} \right) \right] \right\} \quad (1)$$

where:

$$X = \frac{2 \cdot \rho_r \cdot \tan\phi}{r_0 \cdot \lambda}$$

$$\beta = \frac{I_{roof}}{I_{roof} + I_{ground}}$$

$$\alpha = \frac{4 \cdot \pi \cdot B}{\lambda \cdot r_0 \cdot \cos\phi}$$

B - is the orthogonal component of the baseline

I_{roof}, I_{ground} - intensity of return from roof and ground respectively

λ - is the wavelength of the radar

r_0 - is the range to the target

ρ_r, ϕ, H - as shown in Figure 3

From equation (1), we can deduce a couple of things. First, the height of the building will be biased to the stronger return area. If the roof has the stronger return, we will tend to estimate the roof height. The converse is true for brighter ground returns. Equation (1) proves the statement that we made earlier; namely, that if the ground and roof returns are similar, we will get a height in between.

Second, the magnitude of the coherence also contains geometry information in it. As an example, if β goes to 0.5, then the magnitude of the coherence is modulated by a cosine function whose frequency is determined by the height of the building. Hence, the coherence can be used as an indicator of problems due to layover. This phenomenon is strongly related to the volume-scattering effect discussed in [5] and other articles. Figure 4 shows an example of this drop in coherence for the Hirschhorn museum in Washington D. C.

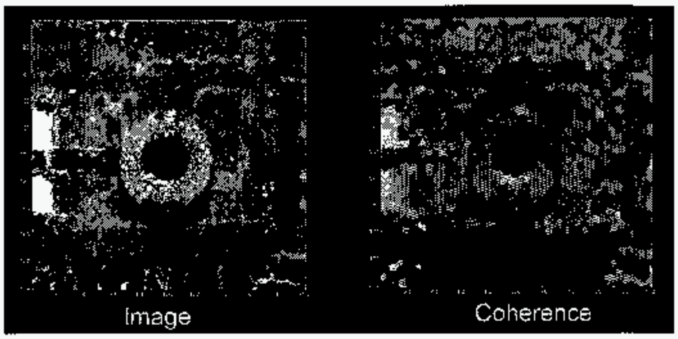

Figure 4: Backscatter and Coherence Images of the Hirschhorn Museum

The implication of equation (1) is that we can take advantage of the of the coherence to detect areas where we are receiving information from more than one target within the same range-Doppler bin. We found that we could use this coherence drop in generating the DEM of the Washington D. C. mall area. We did this by flying our IFSAR on opposite sides of the mall and registering the images. We then chose each height pixel value based upon the highest coherence. By doing this, we chose returns from the side which was least affected by layover. This reduced the problems that we had from the smeared-out fronts of the building resulting from the "front-porch" effect. Figure 5 shows the resulting height map.

Conclusions

In conclusion, we have discussed a number of challenges that commonly arise in attempting to form DEMs of buildings using IFSAR. We dwelled on the issues which crop up from the slant range geometry of IFSAR and layover effects. We presented some ideas of how the IFSAR data could be used to avoid, or at least identify, the layover problems.

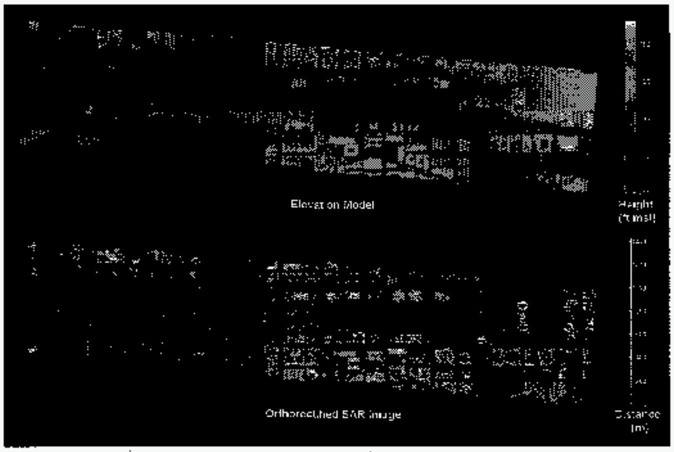

Figure 5: DEM of Washington D. C. Mall Area

Acknowledgments

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