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Ultra high resolution spotlight synthetic aperture radar

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ABSTRACT

We consider the application of a spotlight-mode synthetic aperture radar (SAR) imaging technique to the problem of high-resolution imaging. This approach offers improved image quality, compared with conventional processing, at the expense of slightly increased computational effort. It synthesizes high-resolution terrain maps using data gathered from multiple observation angles. The signal recorded at each transmission point is modeled as a portion of the Fourier transform of a central projection of the imaged ground area. Reconstruction of a SAR images are accomplished using signal processing algorithms from CAT. This model permits a simple understanding of SAR imaging, not based on Doppler shifts. Resolution, sampling rates, waveform curvature, the Doppler effect, and other issues are also discussed within the context of this interpretation of SAR.

Key words: Spotlight, synthetic aperture, radar

1. INTRODUCTION

Synthetic Aperture Radar (SAR) is an active sensing system that uses a series of electromagnetic pulses transmitted and received over time from a moving platform to create an image (Jungang Yang et al. 2012; Mason et al. 2012). SAR differs from Real Aperture Radars (Strozzi et al. 2012; Jinchen Guan et al. 2012), by creating a large virtual antenna, known as the synthetic aperture, which allows tight focusing of the virtual beam along the direction of travel, known as the along track direction. This allows a SAR system to achieve much higher image resolution in the along-track direction than is possible with a RAR system (Yuanyue Guo et al. 2012). In particular, the SAR spotlight mode is able to obtain a high geometric azimuth resolution by steering the radar antenna beam during the raw data acquisition interval, to always illuminate the same area on the ground (Eineder et al. 2009; Prats et al. 2010). This azimuth steering allows the sensor to obtain a longer synthetic array without reducing the real antenna azimuth size (Martinez Lorenzo et al. 2011). In the stripmap mode, the same antenna reduction would require an increase in the pulse repetition frequency (PRF), to avoid aliasing and a corresponding reduction in the range swath, to avoid range ambiguity problems; conversely, in the spotlight mode the higher azimuth resolution can be obtained without increasing the PRF, thus avoiding any corresponding increase of the data rate and also avoiding range ambiguity problems (Benson et al. 2012; Huaping Xu et al. 2012). This advantage is paid with an azimuth reduction of the illuminated area and an increase of complexity of data processing needed to obtain the final high resolution image (Yang et al. 2013). Different approaches have been proposed in the last years to process spotlight SAR data that form a longer synthetic aperture as shown in Figure 1. As more pulses are used, the azimuth resolution increases. It is usually at the expense of spatial coverage, as other areas within a given accessibility swath cannot be illuminated while the radar beam is spotlighting over a particular target area.

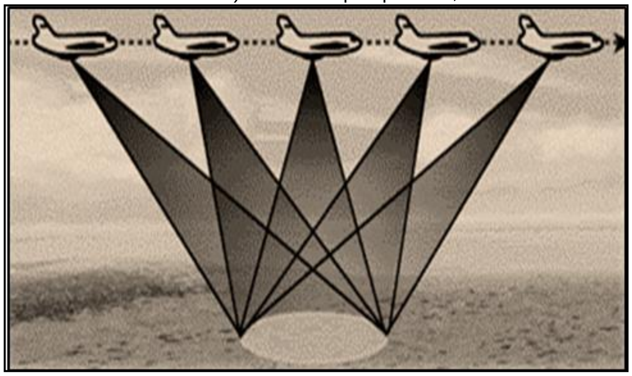

Figure 1
Conceptual view of Spotlight SAR

2. RADAR SYSTEM

In a radar system, resolution in the range direction is

$$\rho_R = \frac{cT}{2} \tag{1}$$

where c is the speed of light, T is pulse duration. Ground range resolution ρ_{GR} , refers to the resolution of the radar projected onto the ground surface, which varies with the grazing angle, γ the angle between the ground surface and the direction of travel of the radar

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energy. The ground range resolution is always coarser than the slant range resolution, and the ground range resolution becomes poorer at nearer ranges.

$$\rho_{GR} = \frac{\rho_R}{\cos(\gamma)} = \frac{cT}{2\cos(\gamma)} \qquad (2)$$

To measure returns of objects that lie orthogonal to the range direction, a real aperture system will change the position or pointing of the antenna either electronically or mechanically. The one way 3dB beamwidth of the real antenna is

$$\theta_{13} \approx \frac{K_a \lambda}{D} \qquad (3)$$

Where D is antenna size in the cross range direction λ is the transmitted wavelength and K_a is the excess bandwidth factor due to antenna weighting.

3. SAR SYSTEM

In a SAR application the antenna beamwidth and phase must be considered over a two-way

$$\theta_{23} \approx \frac{K_a \lambda}{2D} \qquad (4)$$

The spatial separation required for objects to be in separate beam locations depends on both the antenna beamwidth and the distance from the antenna. For real aperture system, resolution in the azimuth direction is

$$\rho_{ra} = R_0 \theta_{23} \approx R_0 \frac{K_a \lambda}{2D}$$

where R_0 is distance between antenna and slant range. Since the azimuth resolution is inversely proportional to antenna size and proportional to range to the target, long range imaging at even moderate resolution may require an antenna size that exceeds what can be practically built. The energy contained in the pulse is proportional to its duration and power, short pulses require large powers to maintain signal-to-noise ratio. Modern radar systems overcome peak power limitation by employing a coded long duration pulse. This coded or chirped pulse has an imposed modulation that allows the return pulse to be "compressed" in time. After compression the effective slant-plane range resolution becomes

$$\rho_R = \frac{K_r c}{2B} \qquad (5)$$

where B is the bandwidth of the chirped pulse, and K_r is an "excess bandwidth factor" to compensate for main lobe broadening caused by signal processing (window weighting). Further, it is required that the return signal from the transmission at one location has completely decayed before listening at another location lest there be interference and a corrupted signal reconstruction.

4. SYSTEM DESIGN

The spotlight synthetic aperture radar mode can improve azimuth resolution by increasing the synthetic aperture time, and its azimuth beam is steered during the whole acquisition time. The major drawback of such configuration is that azimuth beam pointing always at the same area limits the extension of the illuminated area in azimuth. The sliding spotlight mode allows a comprise between azimuth resolution and azimuth extension of imaged scene and it can be described as using a virtual rotation center which is further away from the radar than the imaging scene. A SAR raw data simulator is an important tool for testing system parameters, imaging algorithms, and mission planning. SAR raw data can precisely be generated target by target in the two-dimensional (2D) time domain. However, to the raw data simulation of extended scenes, this approach is of low efficiency. In order to improve the efficiency of raw data simulator, a series of simulators for different imaging modes are proposed in the 2D Fourier domain. Unfortunately, different from the stripmap and the pure spotlight modes, the raw data of extended imaged scenes in the sliding spotlight mode may not efficiently be evaluated in the 2D Fourier transformed domain. The 1D range Fourier domain approach for the sliding spotlight mode is less efficient, compared with the 2D Fourier domain simulators. Azimuth varying band-pass filter (BPF) could be adopted for extracting the desired signals from the raw data in the wide-beam imaging modes and set others to zero. This filter should just accommodate the Doppler centroid varying rate and be independent of the slant range, and it can efficiently be implemented by de-rotation operation and BPF. The design is a complicated endeavor that ensures that the signals from the various array elements (i.e., the pulses received at each vehicle location) are correctly recorded and that there is sufficient data to remove various "corruptions", most notably motion of the vehicle. The image formation processor applies various corrections that ensure that signals from scatterers align and compress properly. It is instructive to consider the limitations and capabilities of a SAR system in terms of the synthetic aperture generated by the collected pulses. Limitations on the maximum length depend on the mode of collection. The illuminated area can be anywhere in the acquisition region of the SAR. This means that the synthetic aperture length is not constrained by the real aperture beamwidth and can, therefore, be very large. This can result in significantly better resolution. The azimuth resolution is

$$\rho_a \approx \frac{K_a R_{S} \lambda_R}{2L_{SA} \sin(\alpha)} \qquad (6)$$

Where R_{SR} is the slant range, L_{SA} is the length of the synthetic aperture, α is the Doppler cone angle. It is often convenient to remove the apparent dependency on the R_{SR} by the angle subtended by the synthetic aperture is

$$R_{SR} \tan\left(\frac{\Delta\theta}{2}\right) \approx \frac{L_{SA}}{2} \sin(\alpha) \qquad (7)$$

Where $\Delta\theta$ is angular interval subtended by synthetic aperture length L at scene center, assuming that the angle $\Delta\theta$ is small so we can approximate the tangent with a sine, we have

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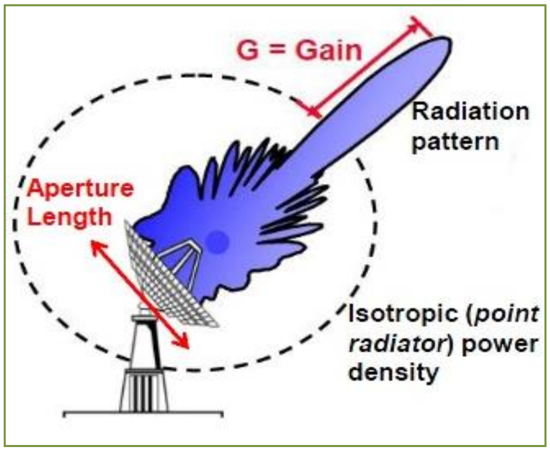

Figure 2

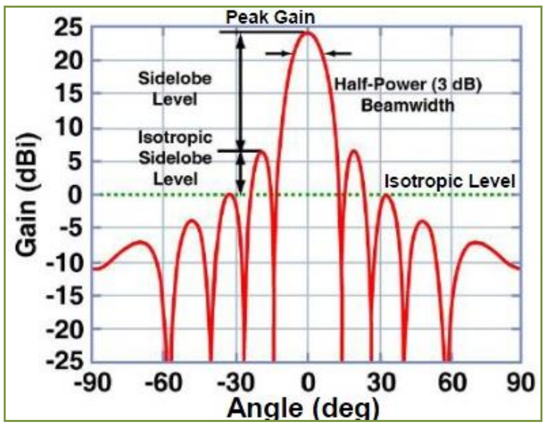

Figure 3

Angle vs Gain

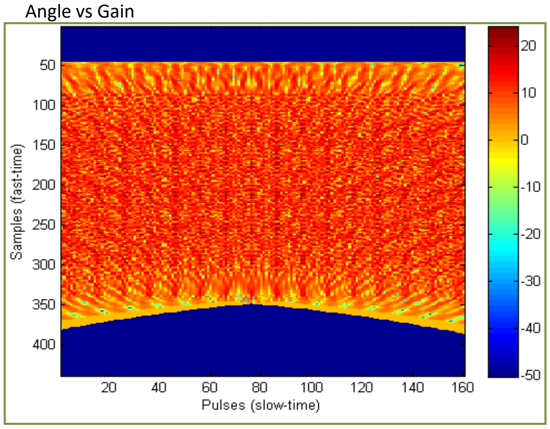

Figure 4

Spotlight returns

$$\rho_A \approx \frac{K_a R_{SR}\lambda}{2L_{SA}\sin(\alpha)} = \frac{K_a\lambda}{4\left(\frac{L_{SA}}{2R_{SR}}\sin(\alpha)\right)} \approx \frac{K_a\lambda}{4\sin\left(\frac{\Delta\theta}{2}\right)} \quad (8)$$

Hence, the resolution can be greatly improved by increasing the dwell time (i.e., the time that is spent illuminating the same target area) by moving the antenna beam. This imparts additional complexity in the antenna system to either electronically or physically steer the real antenna aperture.

5. STRIPMAP MODE

In stripmap mode, the antenna pointing is fixed relative to the flight path. The L_{SA}, is equal to the real antenna beam width on the ground at the location (range) of the scatterer.

$$L_{SA} = R_{SR}\theta_R \approx R_{SR}\frac{K_{Ra}\lambda}{L_R} \quad (9)$$

where θ_R is the angular beamwidth of the real aperture antenna, L_R is the real aperture antenna length, the azimuth resolution of the stripmap mode SAR as

$$\rho_a \approx R_{SR}\frac{K_{sa}\lambda}{2L_{SA}\sin(\alpha)} = R_{SR}\frac{K_{sa}\lambda}{2R_{SR}\frac{K_{ra}\lambda}{L_R}\sin(\alpha)} = K_a\frac{L_R}{2\sin(\alpha)} \quad (10)$$

The distance from the antenna to a target at scene center at this broadside point is R_0. The slant range for a pulse is

$$R = \sqrt{R_0{}^2 + (x - x_0)^2} \quad (11)$$

where x_0 is the position of antenna at broadside, x is the position of antenna for given pulse. If we expand in a Taylor series about the point x_0

$$R \cong R_0 + (x - x_0)R'(x_0) + \frac{(x - x_0)^2}{2}R''(x_0) \quad (12)$$

where R´ first derivative of R with respect to x evaluated at x_0, R˝ is the second derivative of R with respect to x evaluated at x_0. Evaluating we have

$$R'(x)\big|_{x_0} = \left.\frac{x - x_0}{\sqrt{R_0^2 + (x - x_0)^2}}\right|_{x_0} = 0$$

$$R''(x)\big|_{x_0} = \left.\frac{1}{\sqrt{R_0^2 + (x - x_0)^2}} - \frac{(x - x_0)^2}{\left(R_0^2 + (x - x_0)^2\right)^{3/2}}\right|_{x_0} = \frac{1}{R_0} \quad (13)$$

This procedure has two main advantages it reduces the computational load with respect to a time domain simulation; in addition, the procedure is analogous to the existing stripmap simulator, so that most of the algorithms employed and can be reused after minor changes. It must be noted that the presented procedure assumes a straight line flight path. This is usually a good approximation for a few kilometers portion of the elliptical orbit of a spaceborne sensor. Conversely, in the case of airborne sensors appreciable deviations from the ideal trajectory may occur: effects of these deviations are not included in our simulator and arbitrary deviations cannot be accounted for by any Fourier domain simulator. This approach would be useful for instance to identify cases that require motion compensation. However, if a motion compensation algorithm must be tested, use of a point target simulator is sufficient and more appropriate.

6. SIMULATION

The method employed in the simulator has two main advantages: first of all, use is made of efficient FFT codes, thus reducing the computational load with respect to a time domain simulation; in addition, the procedure is analogous to the one used in the existing stripmap simulator, so that most of the algorithms employed in that simulator can be reused after minor changes. It must be noted that the presented procedure assumes a straight line flight path. This is usually a good approximation for a few kilometers portion of the elliptical orbit of a spaceborne sensor. Conversely, in the case of airborne sensors appreciable deviations from the ideal trajectory may occur: effects of these deviations are not included in our simulator and arbitrary deviations cannot be accounted for by any Fourier domain simulator. However, the effect of some particular kinds of deviations from ideal trajectory (e.g., sinusoidal deviations, or sufficiently smooth deviations) can be accounted for by properly modifying the system transfer function. This approach would be useful for instance to identify cases that require motion compensation. However, if a motion compensation algorithm must be tested, use of a point target simulator is sufficient and more appropriate. The application of the proposed simulation scheme to the case of squinted geometry is certainly interesting, because in this case it is known that spotlight processing algorithms often degrade. In the spotlight simulator, the orbit data, scene geometric and electromagnetic parameters are evaluated. The raw signal is computed via a superposition integral in which the reflectivity map is weighted by the SAR system 2-D pulse response. A ground range to slant range projection ensures that foreshortening and layover effects are taken into account whereas a recursive ray-tracing procedure identifies the shadows. In the spotlight case some

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considerations are needed on the evaluation of the incidence angle. The raw signals have been processed by using an algorithm based on the frequency domain, in order to obtain spotlight SAR images. The Figure 2 shows the Antenna Aperture, Figure 3 shows the Angle vs Gain and Figure 4 shows the spotlight returns.

7. CONCLUSION

We have discussed the utility of spotlight mode SAR processing for radar imaging for nearly planar radar motion and a nearly planar scattering surface. The approach avoids motion through resolution cells by affixing a spatial-domain coordinate system. Spotlight SAR data focusing can perform a bulk azimuth raw data compression and to achieve a pixel spacing smaller than the expected azimuth resolution of the fully focused image. Thus, the azimuth spectral folding phenomenon, typically affecting the spotlight data, can be overcome. In this paper, a spotlight SAR raw signal simulator for distributed targets is presented. A proper analytical reformulation of the spotlight SAR raw signal expression is presented. It is shown that this reformulation allows us to design a very efficient simulation scheme that employs fast Fourier transform codes. Accordingly, the computational load will be dramatically reduced with respect to a simulation and this makes spotlight simulation of extended scenes feasible.

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REFERENCES

1. Benson T.M, Campbell D.P, Cook D.A. Gigapixel spotlight synthetic aperture radar backprojection using clusters of GPUs and CUDA. *IEEE Radar Conference.*, 2012, 853-858
2. Eineder M, Adam N, Bamler.R, Yague-Martinez N, Breit H. Spaceborne Spotlight SAR Interferometry With TerraSAR-X. *IEEE Transactions on Geoscience and Remote Sensing.*, 2009, 47,1524-1535
3. Huaping Xu, Zhongyuan Xiao, Jing Gao, Chunsheng Li, Ze Yu. A scanning order design method of jumping spotlight SAR to simplify imaging processing. *IEEE International Geoscience and Remote Sensing Symposium.*, 2012, vol., no., pp.3959-3962
4. Jinchen Guan, Yulin Huang, Jianyu Yang, Wenchao Li, Junjie Wu. Improving angular resolution based on maximum a posteriori criterion for scanning radar. *IEEE Radar Conference.*, 2012, 451-454
5. Jungang Yang, Xiaotao Huang, Tian Jin, Thompson.J, Zhimin Zhou. Synthetic Aperture Radar Imaging Using Stepped Frequency Waveform, *IEEE Transactions on Geoscience and Remote Sensing.*, 2012, 50, 2026–2036
6. L.Yang , Xing M, Wang Y, Zhang L, Bao, Z. Compensation for the NsRCM and Phase Error After Polar Format Resampling for Airborne Spotlight SAR Raw Data of High Resolution. *IEEE Geoscience and Remote Sensing Letters.*, 2013, 10, 165-169
7. Martinez-Lorenzo J.A, Rappaport C.M, Quivira F. Physical Limitations on Detecting Tunnels Using Underground-Focusing Spotlight Synthetic Aperture Radar. *IEEE Transactions on Geoscience and Remote Sensing.*, 2011, 49, 65-70
8. Mason D.C, Davenport I.J, Neal J.C, Schumann, Bates P.D. Near Real-Time Flood Detection in Urban and Rural Areas Using High-Resolution Synthetic Aperture Radar Images. *IEEE Transactions on Geoscience and Remote Sensing.*, 2012, 50, 3041–3052
9. Prats P, Scheiber R, Mittermayer J, Meta A, Moreira A. Processing of Sliding Spotlight and TOPS SAR Data Using Baseband Azimuth Scaling. IEEE *Transactions on Geoscience and Remote Sensing.*, 2010, 48, 770-780
10. Strozzi T, Werner. C, Wiesmann.A, Wegmuller.U. Topography Mapping With a Portable Real Aperture Radar Interferometer. *IEEE Geoscience and Remote Sensing Letters.*, 2012, 9, 277–281
11. Yuanyue Guo, Dongjin Wang, Xuezhi He, Bo Liu. Super resolution imaging method based on random radiation radar array. *IEEE International Conference on Imaging Systems and Techniques.*, 2012, 1-6

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