3-D RANGE STACKING ALGORITHM FOR FORWARD-LOOKING SAR 3-D IMAGING

TAN WeiXian¹,²,³, Hong Wen¹,², Wang YanPing¹,² and Wu YiRong¹,²

¹ The National Key Laboratory of Microwave Imaging Technology (MITL), Beijing 100080, China
² Institute of Electronics, Chinese Academy of Sciences (IECAS), Beijing 100080, China
³ Graduate University of Chinese Academy of Sciences (GUCAS), Beijing 100080, China
Email: xiantantan@163.com

1. INTRODUCTION

The concept of Forwarding-looking Synthetic Aperture Radar (F-SAR) was proposed by Witte [1, 2] at the beginning of 1990's. The first experimental system for F-SAR, SIREV (Sector Imaging Radar for Enhanced Vision), was developed by Witte etc. [1–5] at German Aerospace Center. However, the two-dimensional (2-D) images have been obtained with the SIREV system using the Extended Chirp Scaling (ECS) [3] algorithm.

In this paper, a three-dimensional (3-D) F-SAR imaging algorithm, which is the extension of the two-dimensional (2-D) range stacking algorithm (RSA) and allows the accurate image reconstruction without any interpolation and geometric correction, is introduced for F-SAR system. Additionally, the spatial-varying and spatial-shift properties of the 3-D spread point function (PSF) of Forwarding-looking SAR are revealed for the first time in the paper with the analytical expression. Thirdly, the simulation experiment is performed to demonstrate the validity of the 3-D RSA and characteristics of the 3-D PSF of F-SAR. Finally, the conclusion is given and the future work is outlined.

2. FORWARDING-LOOKING SAR GEOMETRY AND SIGNAL MODELING

We define the OXYZ coordinates system and consider the imaging scenario in a 3-D spatial domain in Fig. 1 (a), where X-axis, Y-axis and Z-axis refer to the ground-range, the azimuth (flight direction) and the elevation direction, respectively. For analyzing the PSF of F-SAR, another coordinates system PUVW of the point target is defined in Fig. 1 (a), and $K_U, K_V, K_W$ is the corresponding wavenumber space. V-axis is the line-of-sight of the sensor and is located at the slant-range plane. W-axis is perpendicular to the slant-range plane. W is perpendicular to the U-V plane. Assume the emitted signal is narrow band linear Frequency Modulated (FM) chirp pulse or stepped frequency wave. The antennas are positioned at $(x_c, y_c, z_c)$. The point target P is located at $(x_n, y_n, z_n)$ with reflectivity $f(x_n, y_n, z_n)$. The echoed signal without considering the antenna pattern and the electromagnetic wave attenuation from the scattering point is

$$s(x, y, z) = \sum f(x_n, y_n, z_n) \left\{ p \left( t - 2\sqrt{(x - x_n)^2 + (y - y_n)^2 + (Z_c + z_n)^2} / C \right) \right. $$

$$+ \left. \exp \left( -j2\sqrt{(x - x_n)^2 + (y - y_n)^2 + (Z_c + z_n)^2} / K_w \right) \right\} .$$

3. FORMULATION OF 3-D RANGE STACKING ALGORITHM AND THE 3-D PSF

In this section, we extend the 2-D RSA [6] to the 3-D version for F-SAR 3-D image reconstruction. The 3-D RSA for F-SAR forms the target function along the ground-range at the individual elevation cell firstly, then forms the target function on the ground-range and the elevation plane via the ground-range IFFT, and finally forms the target function in 3-D space via the azimuth IFFT. The detailed steps are shown in Fig. 1 (b). With 3-D RSA, the illuminated area can be reconstructed without any interpolation and geometric correction. Then the 3-D PSF of F-SAR is derived in the 3-D wavenumber domain.

The transformation between spatial wavenumber domain $K_U, K_V, K_Z$ and $K_U, K_V, K_W$ can be performed via

\cos \varphi_c & \sin \varphi_c & 0 \\
-\sin \varphi_c & \sin \theta_c & \cos \varphi_c \\
-\cos \varphi_c & \cos \theta_c & -\sin \varphi_c
\end{bmatrix} [K_U, K_V, K_W]^T$$
Usually, the support of the target in the wavenumber domain is an approximate regular cube. Therefore, the 3-D Point Spread Function (PSF) can be denoted as

\[
PSF \sim \sin \left( \frac{B_n \mu}{2\pi} \right) \sin \left( \frac{B_n \nu}{2\pi} \right) \sin \left( \frac{B_n \lambda}{2\pi} \right),
\]

where \([\mu, \nu, \lambda]^T = A^{-1}[(x-x_0, y-y_0, z-z_0)]^T\), \(B_n\mu\), \(B_n\nu\) and \(B_n\lambda\) is the wavenumber support bandwidth along the X-axis, Y-axis and Z-axis, respectively. In addition, \(B_n\mu\), \(B_n\nu\) and \(B_n\lambda\) varies with the position of the target. Therefore, the PSF is the spatial-shift and the resolution is spatial-varying.

4. SIMULATION EXPERIMENT

Assume the system works at Ka band, flying at altitude 1500m, with azimuth incidence angle \(\theta\) ranging from 44.85° to 45.15°, the length of the linear antenna is 10m. The transmitted signal width is 150MHz. \(X_0 = 800.00m\). The orientation of the PSF is governed by \(A\). As for the case of targets at the plane \(x=0\), the angle \(\phi_0\) is equal to 0, so the orientation is only determined by \(\theta_0\), as shown in Fig. 2 (a). But as for the other targets, the orientation of the PSF is governed by \(\theta\) and \(\phi\). In the simulation in the paper, only a small part of the observed area (ground-range 40m \(\times\) azimuth 200m \(\times\) elevation 40m) shown in Fig.2 (c) is selected to be reconstructed with the 3-D RSA considering the data volume. The processed result is shown in Fig. 2 (d). As the azimuth incidence range is very small, the sector area is not apparent in this experiment. Note that the image is reconstructed in the 3-D space without any geometric correction with the 3-D RSA.

5. REFERENCES