GEOMETRIC SIMULATION OF SAR IMAGE WITH SRTM

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ABSTRACT: Since the very high resolution synthetic aperture radar (SAR) sensors onboard, the potential to utilize SAR images is increasing. The TerraSAR-X satellite has 3 m spatial resolution in stripmap mode, which is better than traditional sensors. It is necessary to orthorectify the SAR images before manipulating images with other sources.
To orthorectify images, the connection between image and digital elevation model (DEM) are always needed. In the past, ground control points (GCPs) play an important role to connect image and DEM. However, in the case of SAR images, the GCPs are difficult to identify and their ground coordinates are also hard to acquire.
In this study, we introduce a connection between an image and digital elevation model, which is a simulated SAR image. As the German Aerospace Center (DLR) provided the rigorous parameters of orbit, we utilize DEM from SRTM to simulate the SAR image with the Doppler and range equations. Afterward, the combination of real image and DEM can achieve by using scale invariant feature transform (SIFT) to transform the simulated image and real image.

1. INTRODUCTION

Imaging radar systems have advantage to detect and record information of land with all-weather. Since the very high resolution SAR sensors onboard, such as TerraSAR-X and COSMO-SkyMED, the resolution of SAR images is up to 1 m, so that the applications of SAR are widely extend. The ortho-rectificaiton of SAR images is important before integrating the images with other sources. The traditional way to ortho-rectify the images is using identical ground control points in the image and in a map projection (Leberl, 1986). But the difficulty to identify the control points in the SAR images is that the points are hard to recognize and measure precisely in SAR image. The solution is to make a connection between the image and homologous DEM, which is a simulated image from DEM, but the control points.

To simulate an SAR image, two major components need to be considered, which are geometry of image and the radiometry of each pixel, that is to say, the gray value of pixel. As collinearity equation of optical image, the radargrammetry equation presents the geometric principle of SAR image. The equations are already well-defined, and we implement the equations to the actual case.

On the other hand, the intensity of backscatter will contribute the radiometric part of image, brightness or darkness. The interaction of rays and surface, which means the incidence angle of rays, surface roughness and material properties of the target, will cause the different types of reflection, such as specular or Lambertian. These reflections are major reason affect the intensity of backscatter.

In this paper, we focus on simulating the accurate geometry of an SAR image, and relative gray value to each pixel. The radargrammetry equations combine the coordinate systems between object space and image space. On account of TerraSAR-X provides the precise orbit data, we can achieve the position and attitude of antenna on satellites by interpolating the time interval.

The relative gray value of pixels is determined by the slope and aspect with the resampled SRTM DEM. Rather than simulating absolute radiometric effects related to material properties and surface roughness, it suffices to represent the geometry of the scene and to approximate the relative differences in backscatter. (Brunner, 2011) In space-based remote sensing, the intermediate bands (X, C, and L) are therefore the most widely used. We choose X band to simulate the SAR image, which is adaptive to administer cartography and detection. (Maitre, 2008) In this study, there are three steps of simulation 1) the radargrammetry derivation, 2) determination of image coordinates and 3) to establish the gray value of each pixel.

2. METHODOLOGY

2.1 Radargrammetry

The foundation of radargrammetry equation is vector addition. Let us considering the geometry of radar image as shown in Fig. 1. We define the object-space with denoting the origin O and basis vector $<\mathbf{e}_1 \quad \mathbf{e}_2 \quad \mathbf{e}_3>$. The $\mathbf{s}$ is a vector pointing out the position of antenna S and $\mathbf{r}$ is a vector as ray transfer from antenna along the range direction to the target point P. We can achieve the position of P with vector addition by

$$\mathbf{p} = \mathbf{s} + \mathbf{r} \tag{1}$$

Basically, we have to consider the $\mathbf{r}$ within the satellite space coordinate system. In space coordinate system, the origin is S with unit vector $<\mathbf{u} \quad \mathbf{v} \quad \mathbf{w}>$, so that the $\mathbf{r}$ is given by inner product of coordinate $\mathbf{p}^*$ and unit vector $<\mathbf{u} \quad \mathbf{v} \quad \mathbf{w}>$

$$\mathbf{r} = P_u\mathbf{u} + P_v\mathbf{v} + P_w\mathbf{w} = \mathbf{A}\mathbf{p}^* \tag{2}$$

Furthermore, in Fig. 2, the dentition of coordinate $\mathbf{p}^*$ is below:

$$\mathbf{p}^* = \begin{bmatrix} P_u \\ P_v \\ P_w \end{bmatrix} = \begin{bmatrix} |\mathbf{r}|\sin\tau \\ |\mathbf{r}|(\sin^2\Omega - \sin^2\tau)^{1/2} \\ -|\mathbf{r}|\cos\Omega \end{bmatrix} \tag{3}$$

Actually, the unit vector in satellite space transfer from object space, the direction of vector $\mathbf{u}$ presents the satellite's flying direction, which stands for velocity direction. The vector $\mathbf{v}$ is perpendicular to the nadir direction and to the $\mathbf{u}$. The third axis direction $\mathbf{w}$ is the outer product of $\mathbf{u}$ and $\mathbf{v}$. All of them are the function of time *t*. It results in

$$\mathbf{A} = \begin{bmatrix} \mathbf{u}^T \\ \mathbf{v}^T \\ \mathbf{w}^T \end{bmatrix} = \begin{bmatrix} u_x(t) & u_y(t) & u_z(t) \\ v_x(t) & v_y(t) & v_z(t) \\ w_x(t) & w_y(t) & w_z(t) \end{bmatrix} \tag{4}$$

where

$$\begin{aligned} \mathbf{u} &= \dot{\mathbf{s}}/|\dot{\mathbf{s}}| \\ \mathbf{v} &= (\mathbf{s}\times\dot{\mathbf{s}})/|\mathbf{s}\times\dot{\mathbf{s}}| \\ \mathbf{w} &= (\mathbf{u}\times\mathbf{v})/|\mathbf{u}\times\mathbf{v}| \end{aligned} \tag{5}$$

The radargrammetry equation concludes from equation (1) to (5):

$$\begin{bmatrix} P_x \\ P_y \\ P_z \end{bmatrix} = \begin{bmatrix} S_x \\ S_y \\ S_z \end{bmatrix} + \begin{bmatrix} u_x(t) & u_y(t) & u_z(t) \\ v_x(t) & v_x(t) & v_x(t) \\ w_x(t) & w_x(t) & w_x(t) \end{bmatrix} \begin{bmatrix} |\mathbf{r}|\sin\tau \\ |\mathbf{r}|(\sin^2\Omega - \sin^2\tau)^{1/2} \\ -|\mathbf{r}|\cos\tau \end{bmatrix} \tag{6}$$

The image arrangement are known as function o time *t* and due to measurements of navigation data. The result of radargrammetry equation can be described in combination of equation (6), which are

$$|\mathbf{p} - \mathbf{s}| = |\mathbf{r}| \tag{7}$$

and

$$\sin\tau = \mathbf{u}\cdot(\mathbf{p} - \mathbf{s}) / |\mathbf{p} - \mathbf{s}| \tag{8}$$

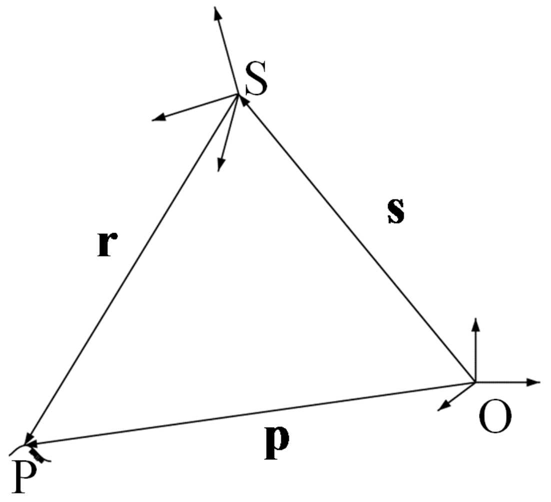

Figure 1 Geometry of radargrammetry in object space coordinate

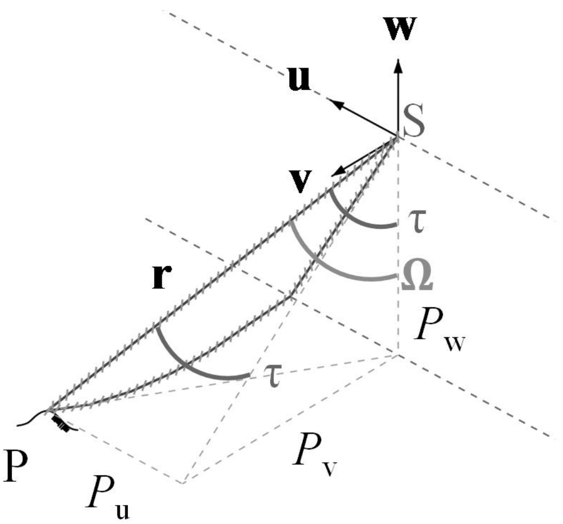

Figure 2 Geometry of satellite space coordinate system

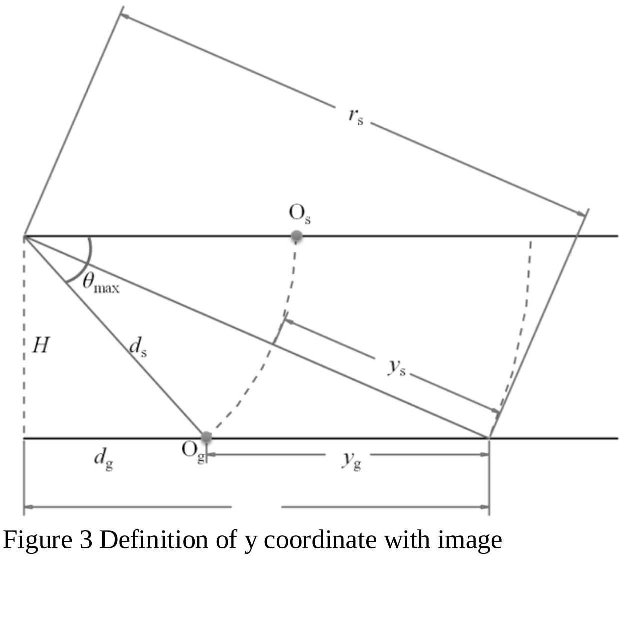

Figure 3 Definition of y coordinate with image

2.2 Image Coordinate System and Object-Space Coordinate System

The definition of image coordinate system is that the x direction is along-track of azimuth direction and the y direction is the cross-track or range direction. The x coordinates are proportional to the time of flight, on the other hand, the y coordinate relates to range between the antenna and an object.

In Fig. 3, the max depression angle ($\theta_{\max}$) and the flying height (H) are already given, thus the nearest slant range (d_s) is

$$d_s = \sin\theta_{\max} / H \tag{9}$$

The O_s and O_g represent the origin of slant rang and ground range respectively. The y coordinate of slant range is

$$y_s = r_s - d_s \tag{10}$$

Discussion of y coordinate, there are the slant range (r_s) and the ground range (r_g) for determination. The sensor scannd the object and recorded the slant range directly. For human vision, it looks much more reasonable by reading image with recording the ground range. The translation of y coordinates between slant range and ground range is

$$y_g = (r_s^2 - H^2)^{1/2} - d_g \tag{11}$$

where d_g is the nearest ground range.

As the x coordinate of image is proportional to the time, we can define the x coordinate for a point P

$$x_p = x_i + (t_p - t_i)(x_{i+1} - x_i) / (t_{i+1} - t_i) \tag{12}$$

2.3 Establish The Gray Value

The interaction of ray and target determine the return power to a radar, that is also cause the gray value of image. The power returned to a radar is given by the radar equation

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 r^4} \tag{13}$$

where the given values are the transmitted power (P_t), antenna gain (G), and wavelength of transmitted pulse (λ); The measurements are range to target (r) and radar scattering cross section (σ). The radar scattering cross section contribute the power returned due to the terrain, which determined by the normal vector of each element in DEM. The normal vector to the surface can be generated from the slope.

3. RESULT

The experiment area is Diao-Yu Island, where locate at north east of Taiwan. We simulated the SAR image of this island with the accurate orbit of TerraSAR and the DEM data of SRTM. Due to the resolution of SRTM DEM is 90 m, we resample the DEM to 3 m by using bilinear interpolation. Fig. 4 shows the simulation result with nearest incidence angle 29.659 in drgree. This result is performance with PCI geomatica software, the programming result will show on the presentation. Contrast to the real SAR image, the simulation result indeed presents reasonable patterns, including the crest line of mountain and bright area., The coastline is discrete, because of the large resolution of SRTM DEM .

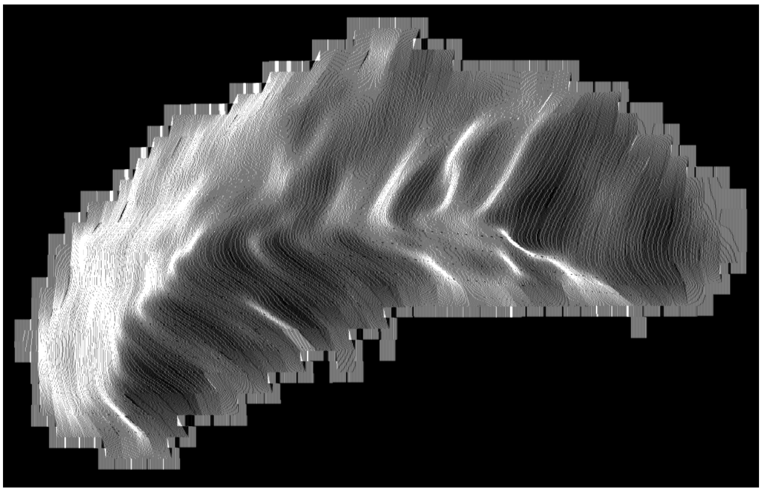

Figure 4 Simulation result

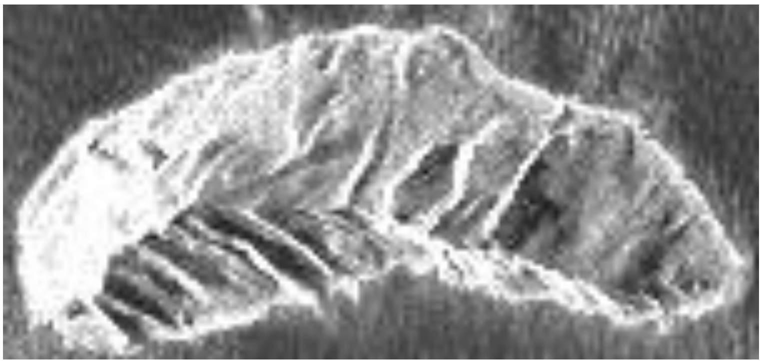

Figure 5 TerraSAR-X image

4. CONCLUSIONS

In this paper, we have proposed radargrammetry to generate the SAR image. Generally, the simulated SAR image is a preprocessing work for ortho-rectify real SAR image so that the relative gray value is enough to presents the geometry of SAR image. If there exits higher resolution DEM, such as generated from cartography or photogrammetry, it will lead to better result of simulation. The grid of SRTM DEM is too large to present the coastline of the island in detail, which brings to surrender major feature area. To implement the practicability of our approach, we will register the real SAR image to the simulated image to discover the ability of ortho-rectify with radargrammetry in the future work.

5. REFERENCES

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