Height Estimation Based Image Compensation Method for Layover Distorted CSAR Image

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***Abstract* - As an advanced operation of synthetic aperture radar (SAR), circular SAR (CSAR) has attracted more and more attentions, because it can achieve higher spatial resolution than conventional linear observation SAR due to considerably larger aperture angle. However, CSAR image is greatly distorted when the target is located away from the central axis position of the circular orbit because of different incident angle from each sub aperture. Such a problem makes it difficult to use the CSAR image for recognition applications. To address with the above problem, this paper presents a layover distortion compensation method for distorted CSAR image by adjusting height of projection planes for each aperture through targets height estimation. The results of simulated and experimental data demonstrate that the proposed method can compensate layover distorted CSAR image in success.**

***Index Terms* — Synthetic aperture radar (SAR), Circular SAR (CSAR), Layover distortion.**

1. Introduction

Synthetic aperture radar (SAR) is a microwave imaging sensor which makes us possible for twenty-four hours monitoring for terrain surface, even in adverse weather. As an advanced operation of SAR, Circular SAR (CSAR) becomes more attractive option due to higher resolution with large aperture angle[1][2]. In a CSAR system, sensor collects scattered signals over a circular flight path. Such an observation way causes larger synthetic aperture angle which leads to higher spatial resolution than that obtained by the conventional linearly observation. Moreover, CSAR has an advantage in the recognition issue, because the linear SAR image is considerably distorted in target rotating along azimuth direction, and is hardly compensated just using image rotation process, while CSAR image is not[3]. Therefore, CSAR is highly useful for automatic target recognition applications, such as, airport surveillance system and suspicious ship monitoring system. As a notable disadvantage from linear SAR, there is a problem that the layover effect of CSAR image is greatly changed when the target is away from the central axis of the circular orbit. This is because each incident angle is going to change according to each sub-aperture region, and the layover situation is then changed for different antenna position[4]. Although this problem is avoided by adjusting a circular orbit with a focus on target on the scanning center, an ideal circularly flight path is difficult to be achieved practically, due to the need of avoiding thunderclouds or legal regulation of flight area. To overcome such difficulty, this paper presents a layover distortion compensation method based on targets height estimation. Concretely, we measure the target height by maximizing a cross correlation coefficient between observed (often off-centered target) and reference (on-centered target) CSAR images. Through both numerical and experimental simulations assuming the 1/200 scale model of X-band radar, we show that our proposed method successfully compensates the image distortion caused by layover without any prior knowledge about target location or shape.

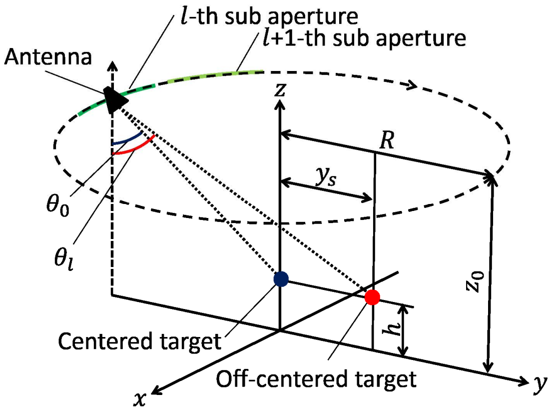

Fig. 1. System model.

2. Proposed Method

The system model is shown in Fig. 1. The plane at $z=0$ denotes a ground plane. An antenna is scanned along circular orbit at the height $z=z_0$. In typical CSAR image reconstruction process, a circular aperture is divided into L-th sub aperture and reconstructed sub images $s_l(x,y,z_l)$ $(z_l=0)$, respectively. Subsequently, a final CSAR image $s(x,y,h)$ $(h=0)$ is obtained by synthesizing sub images incoherently. As mentioned in Sec. 1, in the case of target located at off-centered point, the layover effect is variant with regard to each sub aperture area due to different incident angle. To compensate such distortion, the proposed method introduces the height estimation in order to derive suitable projection plane. The height of target is estimated as;

$$\hat{h} = \arg\max_{h} \rho\left(s_{\mathrm{ref}}(x,y,h_0),\ s_{\mathrm{obs}}(x,y,h)\right), \tag{1}$$

Where $\rho(f(x,y),\ g(x,y))$ denotes cross-correlation coefficient between $f(x,y)$ and $g(x,y)$ along the x and y axes. $s_{\mathrm{ref}}(x,y,h_0)$ is an observed CSAR image assuming a centered target, and $s_{\mathrm{obs}}(x,y,h)$ is a CSAR image, where the height of projection plane as z_l is determined by;

$$z_l = h\left(1-\frac{\tan\theta_l}{\tan\theta_0}\right). \tag{2}$$

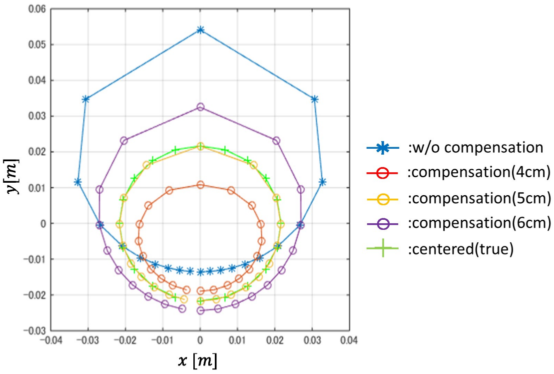

Fig. 2. Compensation for a point scatterer.

Here, θ_l denotes an incident angle for off-centered points from the l th sub-aperture center. θ_0 denote that for on-centered target. In synthesizing the sub CSAR images, the amplitude of each CSAR image is normalized because an image intensity depends on actual distance between antenna and target, which is not consistent in the off-centered target case to that in the on-centered case.

3. Performance Evaluation by Numerical and Experimental Simulations

First, this section describes the performance evaluation through numerical simulation. Numerical simulation model assumes the 1/200 scale model of X-band radar except for the center frequency. Off-nadir angle θ is 65 ◦, the height of scanning plane z_0 = 0.7 m. A single point scatterer is located at h=5 cm. Figure. 2 shows an orbit of estimated point scatterer, which is extracted from the maximum response of CSAR before and after applying the proposed compensation. This figure demonstrates that if a height of scatterer is given, CSAR image can be accurately compensated.

Next, the experimental validation is described as follows. Figure 3 shows the experimental setup. Here, two horn antennas are used as transmitted and received antennas, where each received data is recorded by vector network analyzer (VNA). Frequency is swept from 26 GHz to 40 GHz. Figure. 4 shows image comparison before and after the proposed compensation results scheme, where the 1/200 downsized model for B747 is assumed. Distance from center point to off-centered point is 0.90 m (corresponding to 60 % of scanning radius). This figure shows that the proposed method correctly compensates the distorted CSAR image, that is notable around a nose of airplane. The remained error for compensation is caused by mismatch of sampling interval between on-centered and off-centered case as shown in Fig. 2. This mismatch leads to focused image difference because CSAR image is generated by convolution between these point-wise distributions and PSF function. Fig. 5 shows the cross-correlation coefficient between on-centered and off centered CSAR image, before and after compensation, in changing distance from center point. This result also demonstrates that the proposed method reduces the distortion of CSAR images of off-centered target.

4. Conclusion

This paper proposed a layover distortion compensation method for CSAR images using height estimation of target.

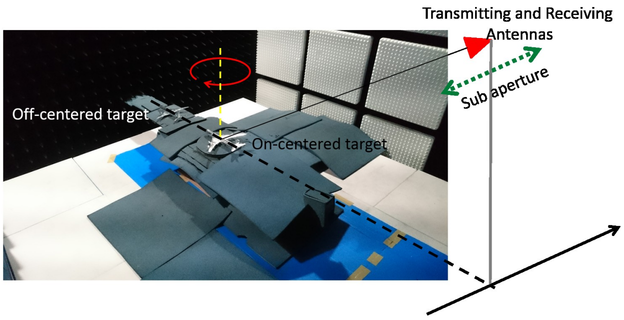

Fig. 3. Experimental setup.

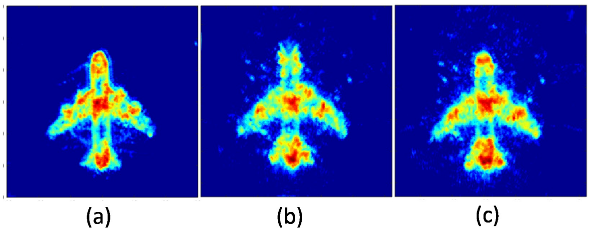
(a) (b) (c)

Fig. 4. Compensation for aircraft model (B747). (a): on-center(reference), (b): off-center(w/o compensation), (c): off-center(w compensation).

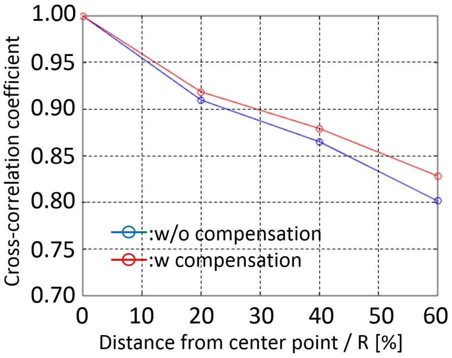

Fig. 5. Comparison of w/o compensation and with compensation based on experiment data.

Future work is validation of the usefulness of the proposed method is validated through ATR problems.

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