AZIMUTH AMBIGUITY DETECTION AND SUPPRESSION IN SAR IMAGES

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ABSTRACT

We propose a novel SAR azimuth ambiguity suppression method. The proposed method is a post process for a SAR image; namely, it does not require any modification to the SAR image formation process nor the SAR system design. Noting that the azimuth ambiguity is blurred in the SAR image, the proposed algorithm refocuses the image to focus the azimuth ambiguity and then automatically detects and identifies the locations, and also the orders, of the ambiguities in the refocused image. After the detected ambiguities in the refocused image are eliminated, the final SAR image is obtained by refocusing back to the true image. Experimental results using true satellite images show that the proposed method successfully suppresses the ambiguities without causing severe degradations to the true images.

Index Terms— SAR, azimuth ambiguity suppression, ambiguity focusing

1. INTRODUCTION

Azimuth ambiguity is inherent in SAR (Synthetic Aperture Radar) imagery, and it is one of the major factors that defines the quality of a SAR image. Although most SAR systems are carefully designed to keep the azimuth ambiguity as low as possible, azimuth ambiguity of a very bright target is almost impossible to be fully eliminated just by the system design. So there is a strong demand for a good azimuth ambiguity suppression method.

One of the azimuth ambiguity suppression methods proposed so far is a spectrum filtering and extrapolation [1]. But this method deteriorates the azimuth resolution. Another method is a subtraction of simulated false images which are calculated from true targets of ambiguity origins [2]. This method, however, requires the precise knowledge of the origin of the ambiguity, which is not available a priori, and is difficult, in most cases, to be estimated from the image that includes the ambiguity to be suppressed.

In this paper, we propose a novel azimuth ambiguity suppression method. The basic idea is to refocus the SAR image to focus the azimuth ambiguity and to eliminate the "focused ambiguity signal" from the refocused image, and then to refocus back to the true SAR image. The advantage of the proposed method is that it automatically detects and identifies the locations, and also the orders, of all the ambiguities in the image to be suppressed. In section 2, the proposed algorithm is explained, and in section 3, the performance of the proposed algorithm is demonstrated using satellite SAR images.

2. PROPOSED METHOD

The proposed method consists of two parts – the ambiguity detection part and the ambiguity suppression part.

Fig. 1 shows the flowchart of the ambiguity detection part. At first, the amplitude of the original SAR image is discarded; namely, the amplitudes of all the pixel is set to be constant, to generate the "phase-only" SAR image. This step is essential so that the focused azimuth ambiguity signal stands out in the refocused image, and it is explained later in this chapter. In the second step, the image is refocused to the k-th order azimuth ambiguity. The detail of the refocusing process is shown in Fig.2. Azimuth FFT is applied to the original SAR image to get the Range-Doppler image. In the Range-Doppler image, the range cell migration of the k-th order azimuth ambiguity signal is given as follows:

$$R_{\Delta}(k, f_{\eta}) = \frac{R_0 \cos\theta_k}{\sqrt{1 - \frac{\lambda^2 (f_{\eta} + k f_{\mathrm{PRF}})^2}{4V_{\mathrm{r}}^2}}} - \frac{R_0}{\sqrt{1 - \frac{\lambda^2 f_{\eta}^2}{4V_{\mathrm{r}}^2}}} \quad (1)$$

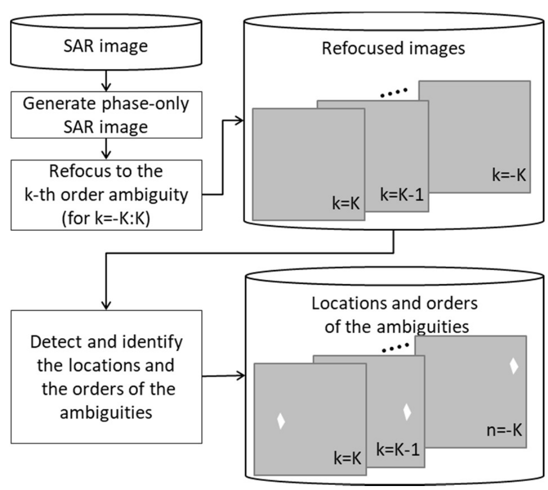


Fig. 1 Ambiguity detection method

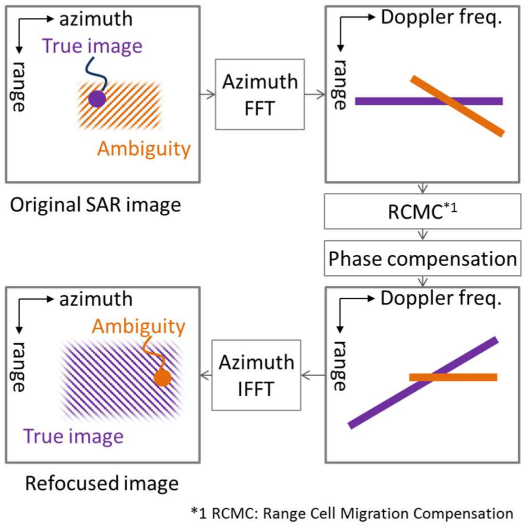


Fig. 2 Image refocus method

where, f_η represents the Doppler frequency, R_0 is the range of nearest approach, λ is the wavelength, V_r is the effective velocity of the platform, and $\cos\theta_k$ is given by:

$$\cos\theta_k = \sqrt{1 - \left(\frac{\lambda k f_{\mathrm{PRF}}}{2V_r}\right)^2} \tag{2}$$

In the range cell migration compensation (RCMC) process, the range migration of the k-th order azimuth ambiguity is compensated, and after the proper phase compensation, azimuth IFFT is applied to get the image focused to the k-th order azimuth ambiguity. Azimuth ambiguity signal is then detected in the refocused images, and the orders k_i and the locations (m_i, n_i) are identified for all the detected ambiguity signals (i=1,2,…,L, where L is the number of the detected ambiguity signals).

Fig.3 illustrates the effect of setting the amplitude constant over the original SAR image. If refocusing process in Fig.2 is applied directly to the original SAR image, the "blurred" signal of the strong true targets often exceed focused ambiguity signal and disturb the detection of the focused ambiguity signal. On the other hand, if we discard the amplitude and apply refocusing process to the phase-only image, there is more chance for the focused ambiguity signal to exceed the blurred true target signal as shown in the lower row of Fig. 3.

Fig.4 shows the flowchart of the ambiguity suppression part. In order to suppress the i-th ambiguity, the original SAR image is refocused to the k_i -th order ambiguity and the signal at (m_i, n_i) is eliminated. This process is repeated for all the detected ambiguity signal, and finally the ambiguity suppressed SAR image is obtained. Note that for azimuth ambiguity suppression process, phase-only image is not generated, in order to preserve the true target signal.

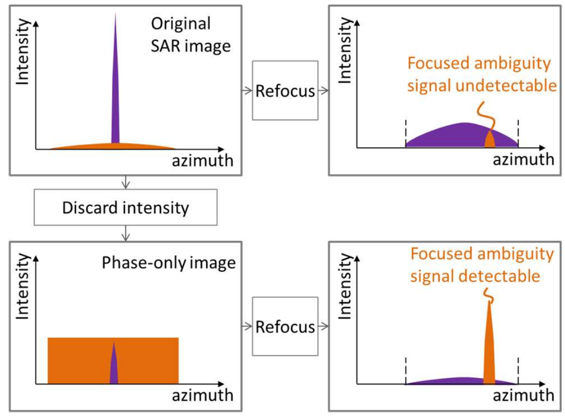


Fig. 3 The effect of discarding amplitude

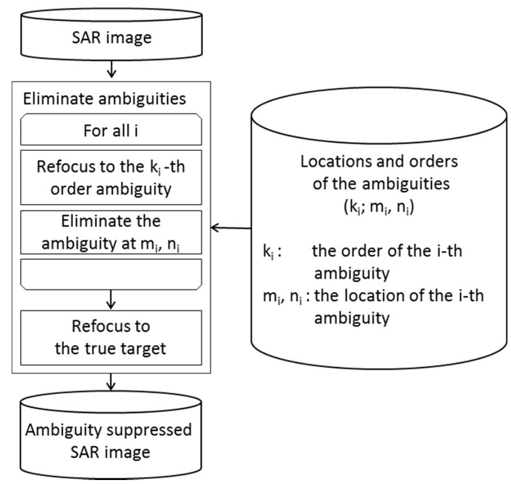
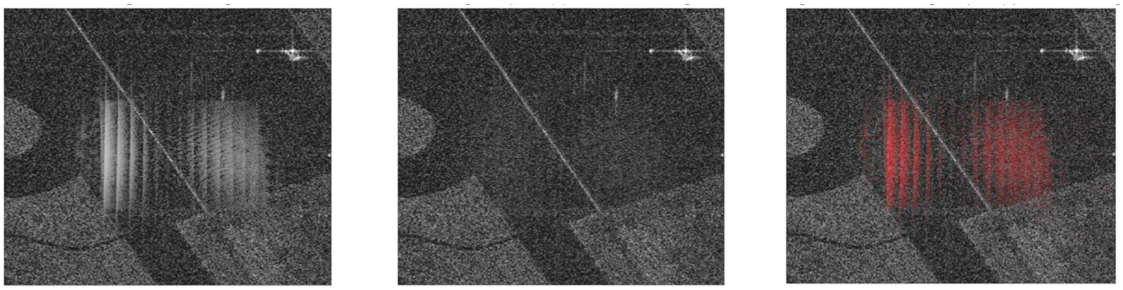


Fig. 4 Azimuth ambiguity suppression method

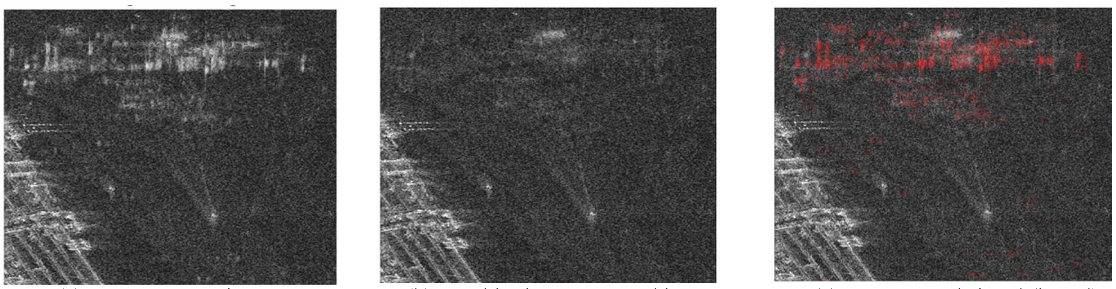
3. EXPERIMENTAL RESULTS

Fig.5 and Fig.6 show the experimental results using true satellite images. Table.1 summarizes the overview of the data used in the experiment. In Fig.5 and Fig.6, (a), (b) and (c) show the original SAR image, azimuth ambiguity suppressed image, i.e., the output of the proposed method and the difference of the original and output images, respectively. In (c), the pixels in red represent the difference between the original and output image; that is, the azimuth ambiguity signal suppressed by the proposed method. In Fig.5 (a), the vertical stripe pattern corresponds to the azimuth ambiguity. One can see that this ambiguity is so strong that it obscures a considerable portion of the image. In Fig.5 (b), the vertical stripe pattern is no longer visible and the signal that was obscured in Fig.5 (a) can clearly be observed. And we can confirm in Fig.5 (c) that the vertical stripe pattern has properly been identified as the azimuth ambiguity signal. In Fig.6 (a), very strong azimuth ambiguity signals from the land area are superposed on the ocean area.



(a) COSMO SkyMed image (b) Ambiguity suppressed image (c) Suppressed signal (in red)

Fig. 5 Ambiguity suppression result (Airport)



(a) TerraSAR-X image (b) Ambiguity suppressed image (c) Suppressed signal (in red)

Fig. 6 Ambiguity suppression result (Harbor)

Table.1 Satellite data used in the experiment

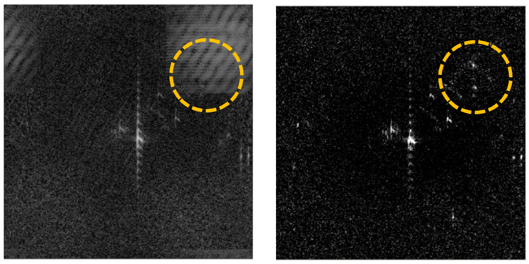
area	Haneda Airport	Nagoya
date	2013/3/10 8:34:28	2017/3/8 21:01:45
satellite	COSMO-SkyMed	TerraSAR-X
mode	SPOTLIGHT-2	Stripmap

In Fig.6 (b) and (c), one can see that the strong azimuth ambiguity signals are well suppressed. Note that the ship signal at the lower middle of the image is well preserved, even though the signal is blurred due to the motion of the ship. Recall that the proposed method refocuses the blurred azimuth ambiguity and eliminate the ambiguity signal in the refocused image. The ship signal is preserved, because the proposed method suppresses the signal that corresponds to the blur specific to the azimuth ambiguity signals.

Fig.7 (a) and (b) show the results of ambiguity focusing process applied to original SAR image (Fig.5 (a)) and phase-only image, respectively. In Fig.7 (a), a strong true target in the upper right of Fig.5 (a) is blurred and covers the focused ambiguity signals in a dashed circle. In Fig.7 (b), the focused ambiguity signals are more visible than in Fig.7 (a).

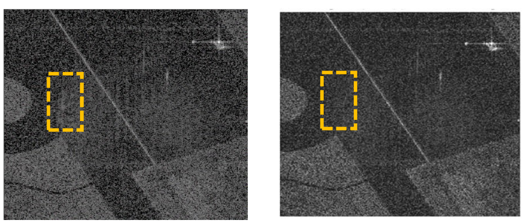
The effect of the phase-only SAR image generation process illustrated in Fig.3 should be evident by comparing Fig.7 (a) and (b). The blurred signals of the strong true target are well suppressed in the refocused image generated from the phase-only image. This is the reason why phase-only image needs to be generated as the first step in the ambiguity detection process.

Fig.8 (a) and (b) show ambiguity suppressed images without and with a phase-only SAR image generation process. Mean power in a dashed rectangular in Fig.8 (b) (Fig.5 (b)) is 3.7 dB lower than Fig.8 (a). It means that a phase-only SAR image generation process makes ambiguity signals clear and enable to remove ambiguity signals accurately.



(a) original image (b) phase-only image

Fig. 7 Ambiguity signal focusing results applied to original SAR image and phase-only SAR image



(a) without a process (b) with a process

Fig. 8 ambiguity suppressed images without and with a phase-only SAR image generation process

4. CONCLUSIONS

A novel SAR azimuth ambiguity suppression method has been proposed. Noting that the azimuth ambiguity is blurred in the SAR image, the proposed algorithm refocuses the image to focus the azimuth ambiguity and then automatically detects and identifies the locations, and also the orders, of the ambiguities in the refocused image. After the detected ambiguities in the refocused image are eliminated, the final SAR image is obtained by refocusing back to the true image. Experimental results using true satellite images show that the proposed method successfully suppresses the ambiguities without causing severe degradations to the true images.

5. REFERENCES

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