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IMPROVED MOTION COMPENSATION FOR WIDE-BEAM WIDE-SWATH AIRBORNE SAR

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Abstract—In order to gain consistent focusing quality all over the imaging region for wide-beam wide-swath airborne synthetic aperture radar (SAR), higher motion compensation (MoCo) accuracy at the edge of the swath is needed. In this letter, an improved MoCo approach is proposed, and its performance is validated by using simulated data, as well as real data collected by a P-band SAR system.

1. INTRODUCTION

In recent years, there is increasing interest in high resolution synthetic aperture radar (SAR) systems operating on small aircraft and Unmanned Aerial Vehicles (UAVs), though the small platforms are more susceptible to atmospheric turbulence. For these systems operating at low frequencies, e.g., the VHF/UHF band, or at higher frequencies (usually more than 1 GHz) with super high azimuth resolution (0.5 m or higher), motion compensation (MoCo) is quite a challenge. One problem comes from the wide-beam azimuth processing of the angular dependent motion errors, which has already been solved by using a sub-aperture MoCo approach [1]. Another problem is that the MoCo accuracy at the edge of the swath is always lower than that at the swath centre (usually corresponding to the reference range), especially when the system works in a wide-swath mode. Moreover, complex motion errors of the small platform during the long aperture time will make the issue even worse. In this letter, an improved MoCo approach for wide-beam wide-swath airborne SAR is proposed and its superior performance is compared with the conventional sub-aperture MoCo approach.

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2. ALGORITHM DESCRIPTION

The classical two-step MoCo [2] performs well in the narrow-beam SAR systems because of the so-called center-beam approximation (CBA) principle [3]. When it is used to process the wide-beam SAR data, however, a sub-aperture MoCo step is needed to compensate the residual azimuth-variant phase errors by dividing the raw data into shortlength azimuth blocks. Although the sub-aperture MoCo has good accuracy at the swath centre, it is difficult to gain consistent focusing quality for the targets all over the swath. This is because the residual motion errors after first-order and sub-aperture MoCo, being zero at the reference range and increasing towards the two edges of the swath, will reduce the range cell migration correction (RCMC) accuracy by range profile shifts and phase modulation errors [4]. The uncorrected RCM error will then cause degradation of the final focusing quality after azimuth compression (AC). This effect can be ignored when the residual motion errors are low-frequency and small-amplitude, and a successive second-order MoCo step after RCMC will be adequate for the focusing accuracy. However, when the system has a wide-swath and the motion errors are large or high-frequency, the focusing quality at the edge of the swath will be affected seriously by the residual motion errors. According to the aforementioned analysis, an improved MoCo approach for wide-beam wide-swath airborne SAR is proposed with the block diagram shown in Fig. 1.

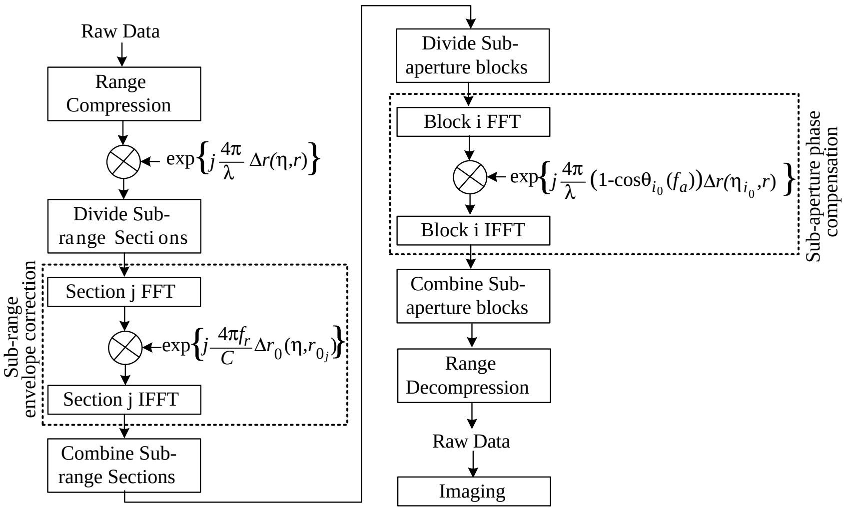

Figure 1. Block diagram of the improved MoCo algorithm.

The first improvement is to compensate the range-invariant and residual range-variant phase errors together in the range-compressed time-domain before RCMC, which is used to eliminate the phase modulation errors of the RCM by the greatest extent. The combined compensation term is

$$H(\eta, r) = \exp\left\{j\frac{4\pi}{\lambda}\Delta r(\eta, r)\right\} \tag{1}$$

where η denotes the azimuth slow time, λ the centre wavelength, and $\Delta r(\eta, r)$ the motion error to the slant range r.

The second improvement is a sub-range envelope correction step to alleviate the range profile shifts caused by the residual motion errors. It is carried out by dividing the data into overlapped range sections and then implementing the envelope correction for each of the sections. When the range-invariant motion error at the centre of the jth section is $\Delta r_0(\eta, r_{0_j})$, and the range frequency is f_r, the jth correction term is

$$H_j\left(f_r, \eta, r_{0_j}\right) = \exp\left\{j\frac{4\pi f_r}{c}\Delta r_0\left(\eta, r_{0_j}\right)\right\} \tag{2}$$

The range length of the data sections must be greater than the range compression (RC) core and the maximum residual range-variant motion errors at the edge of each section can not be larger than half of the range resolution.

In addition to the above two improvements, the sub-aperture MoCo step has to be slightly modified by considering the range dependency of the residual azimuth-variant phase errors. If the motion error at the central position of the ith azimuth sub-aperture is $\Delta r(\eta_{i_0}, r)$ and the azimuth angle is $\theta_{i_0}(f_a)$, which corresponds to a certain azimuth frequency f_a, the modified sub-aperture phase compensation term can be expressed as

$$H_i\left(f_a, r\right) = \exp\left\{j\frac{4\pi}{\lambda}\left(1 - \cos\theta_{i_0}\left(f_a\right)\right)\Delta r\left(\eta_{i_0}, r\right)\right\} \tag{3}$$

After all the MoCo steps have been finished, the data has to be range decompressed to the raw state and then processed by using the image formation algorithm.

3. SIMULATION RESULTS

In the following experiments, the extended chirp scaling (ECS) algorithm is used as the imaging technique [5]. The simulation parameters of a wide-beam wide-swath SAR are listed in Table 1. A point target located 1 km away from the swath centre has been

Table 1. Simulation parameters of a wide-beam wide-swath SAR.

System Parameters	Value
Centre Frequency	500 MHz
Bandwidth	150 MHz
Flight Height	2.5 km
Conference Range	6.5 km
Integration Angle	25°
Swath Width	3 km
Resolutions	1 m × 1 m

Table 2. Imaging quality parameters of the trihedral corner reflector.

	Range Resolution (m)	Azimuth Resolution (m)	2D PSLR (dB)	2D ISLR (dB)
Sub-aperture MoCo	0.95	1.20	−6.13	−2.47
Improved MoCo	0.95	1.11	−10.03	−4.15

simulated by introducing a 1.5 cycles per synthetic aperture length frequency and 20 m amplitude sinusoidal motion error corresponding to the reference range. The simulation results are shown in Fig. 2. The profile of the range compressed data and the contour plots after AC show that the improved MoCo has better RCMC accuracy than the sub-aperture approach, and the focusing result is more similar to the ideal case.

4. P-BAND SAR DATA RESULTS

The data collected by our P-band SAR, which has been mounted on a small aircraft 'Y-12', have been processed by using the ECS algorithm. The swath of the SAR is about 5.2 km, and we have found obvious focusing quality decline at the edge of the swath when the aircraft has strong motion errors. A 1 m trihedral corner reflector is located 1.8 km away from the swath centre, and the imaging results after the sub-aperture MoCo and the improved MoCo are used to evaluate the MoCo performance. The maximum amplitude of the motion error is about 32 m during the whole aperture for the aircraft is likely to experience a sudden strong crosswind. The corresponding images are labeled using

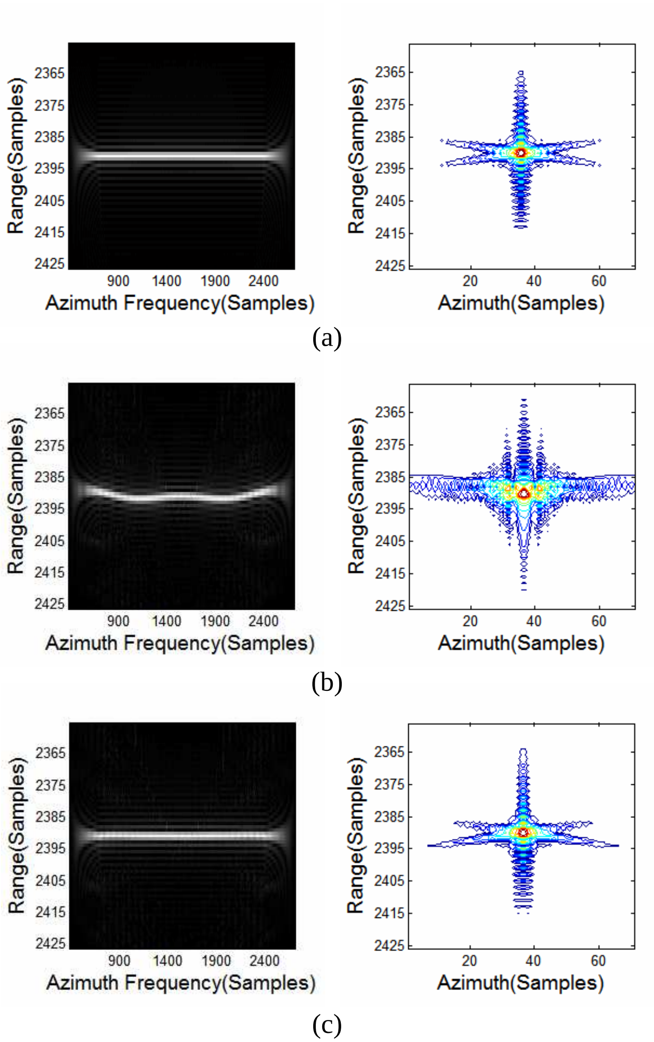

Figure 2. Range compressed data in the range Doppler domain after RCMC and the contour plots after AC. (a) Ideal Case. (b) Sub-aperture MoCo. (c) Improved MoCo.

two circles in Figs. 3(a) and (b), and the azimuth amplitude responses are compared in Fig. 3(c). The measured azimuth resolution after the improved MoCo is 1.1 m, better than the 1.2 m resolution after the sub-aperture approach. In addition, the more symmetrical sidelobe and thinner main lobe indicate a better performance of the improved MoCo approach. The material imaging quality parameters are listed in Table 2.

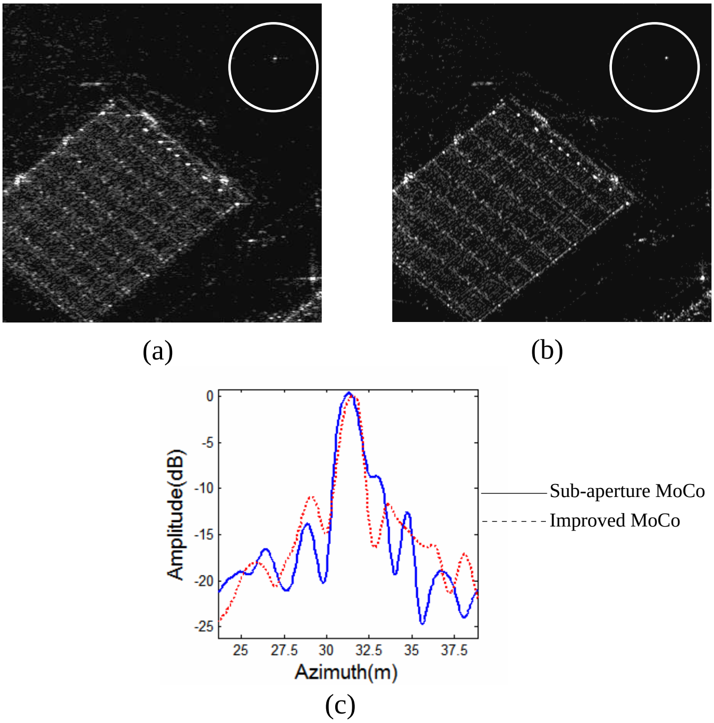

Figure 3. Imaging results of the real data. (a) Sub-aperture MoCo. (b) Improved MoCo. (c) Azimuth amplitude responses.

5. CONCLUSIONS

An improved MoCo approach for wide-beam wide-swath airborne SAR has been presented, and the performance has been demonstrated using simulated, as well as real P-band SAR data. The results show that the proposed MoCo has better accuracy for the targets at the edge of the swath than the conventional sub-aperture approach, which means consistent focusing quality all over the imaging region. The procedure of the algorithm implies that its application is not limited to ECS algorithm; it can be easily implemented with most of the known imaging algorithms without any modification of the imaging flow.

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