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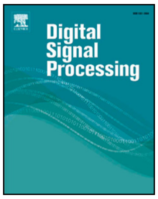

Effective baseline estimation in dual-channel synthetic aperture radar for moving target imaging and relocation

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ABSTRACT

In a dual-channel synthetic aperture radar (SAR) system with the phase centers being positioned along the track, the motion parameters can be obtained by the interferometric phase. When the phase centers of a dual-channel system misalign with the moving track, the interferometric phase depends on the effective baseline length, defined as the projection of the physical baseline on the moving track of the platform. Therefore, the accurate estimation of the effective baseline is crucial for the motion parameter estimation of moving targets in a dual-channel SAR system. This paper proposes a robust model for the estimation of the effective baseline, which considers the motion errors brought by the yaw and rolling of the platform. It also employs an average-median filter to improve the estimated accuracy of the effective baseline in range-compressed domain by considering the error of interferometric phase, such as Taylor approximate expansion, clutter pollution and noise influence. Furthermore, the approach for estimating the along-track and radial velocities of moving targets is presented in detail. The accuracy of the proposed method for effective baseline estimation will be analyzed by the root-mean-square-error (RMSE) compared with the Cramer–Rao bound (CRB). The results by applying the proposed method into a set of real SAR data are consistent with the analysis presented in this paper.

1. Introduction

Characterized by remote sensing capabilities in all weather conditions and all daytime, synthetic aperture radar (SAR) has intensively been investigated for both civil and military applications. The SAR ground moving target indication (SAR-GMTI) can perform imaging and localization of moving targets in the SAR image effectively [1,2]. However, the performance of SAR-GMTI is dependent on the motion parameter of moving targets, because the radial velocity of target induces range walking and azimuth offset in the SAR image, and the azimuth velocity smears the focused target [3–5]. Hence, accurate estimations of motion parameters are desired for imaging and localizing the moving target.

Commonly, a single channel SAR system generates several images by different Doppler looks or filters for GMTI and parameter estimation [6,7]. For a single-channel SAR system, it usually needs to estimate the motion parameters of targets by using computationally heavy search algorithms such as Radon transform (RT), fractional Fourier transform (FrFT) or polynomial Fourier transform (PFT) [8–11]. In order to reduce the computational burden and get the robust performance, the multi-channel SAR (MC-SAR) or dual-channel SAR system has been proven to be a very important tool for GMTI due to its high repeatability and high resolution. Meanwhile, for a dual-channel SAR system with the phase centers being positioned along the track, the motion parameters can be obtained through the interferometry phase, which can considerably reduce the computational load and improve the estimation accuracies of the parameters. However, the phase centers of a dual-channel system may displace from the expected moving track because of some practical factors such as an airborne system moving in the presence of crab angle, and a space-based system with an equivalent crab angle induced by the earth's rotation. In these cases, the interferometric phase depends on the effective baseline length, defined as the projection of the physical baseline on the moving track of the platform. Therefore, the accurate estimation of the effective baseline is crucial for the imaging and relocation of moving targets in a dual-channel SAR system.

In practice, it is difficult to estimate effective baseline directly from the received echoes. For the standard along-track interferometry (ATI) SAR system, where one antenna transmits pulses and all the antennas receive the returns, the equivalent phase center is assumed to be located halfway at between the physical transmit-

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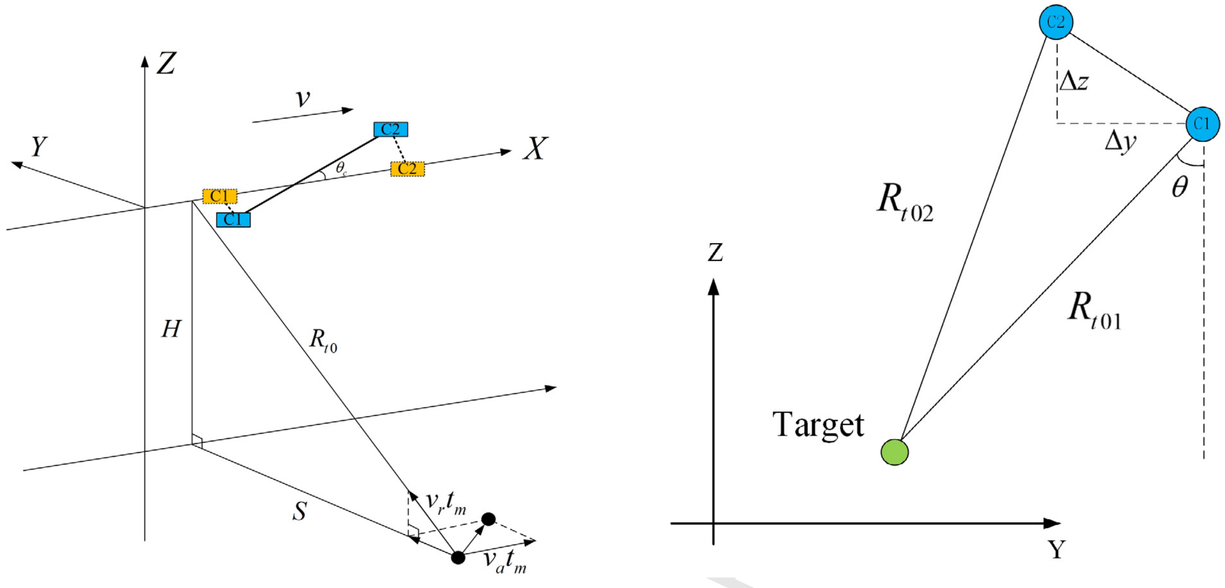

(a) (b)

Fig. 1. (a) The dual-channel sidelooking SAR system with crab angle. (b) The projection of motion error in the elevation plane. (For interpretation of the colors in the figure(s), the reader is referred to the web version of this article.)

ting and receiving phase centers [12–14]. However, the assumed phase center positions are not the effective phase center positions. Additionally, for the distributed small satellite (i.e., constellation satellite) SAR system, the transmitter and receiver can be placed on different satellites, where the along-track baseline is usually coupled with a cross-track baseline and varies with orbit central angles [15]. In the past decades, researchers have made a lot of efforts on the accurate estimation of the effective baseline. An accurate eigen-decomposition based (EDB) method is proposed to exploit the slope of the linear interferometric phase ramp as a pioneer work [16]. The median filtering approach in [17] compensates all radar motion that has radial components. It is shown that the median filter method works well for the data with high signal-to-clutter-and-noise ratio (SCNR), but it is restricted by the low SCNR. The median filter approach does not consider the expectation of the target-and-clutter mixed interferometric phases, which will result in vibration to the interferometric phases. This may severely affect the performance of effective baseline and motion parameter estimation. The definition of the maximum effective baseline is proposed to analyze the degree of coherence between dual channels [18]. But to be noted here, the 'effective baseline' in [18] is the perpendicular baseline which is different from the along-track effective baseline in this paper. The decorrelation of both along-track and cross-track errors, which results from the crab angle, should be considered for the practical application in this paper.

Hence in this paper, a novel method for the effective baseline estimation is proposed, which considers both the along-track and cross-track motion errors. The estimation method of effective baseline can be divided into three steps: First, the cross-track motion phase shift is calibrated by the two-dimensional method, which approximately compensates the cross-track phase shift; second, detect the moving targets via the magnitude and phase (M&P) detector; third, without the effect of the cross-track motion error, an average-median filter method is proposed to improve the estimated accuracy of the effective baseline in range-compressed domain. The interferometric phase of dual-channels is actually a sum of the target, clutter, noise and the cross-terms of the three elements. The proposed average-median filter performs the expectation operation and provides more robust estimations by illuminating both clutter pollution and noise influence compared with the median filter in [18], especially under the low SCNR condition. After estimating the effective baseline, an approach to estimate the along-track and radial velocities of each moving target is also presented, which leads to a finely refocused image and correct relocation of the moving targets. The real SAR data is provided to support the methods and the analysis of the proposed method is presented in this paper.

The rest content of this paper is organized as follows: Section 2 presents the dual-channel SAR signal model with the motion error of the platform. Section 3 describes the specific steps for moving target indication and estimation of the effective baseline and motion parameters. Additionally, how to illuminate the impact of the Taylor expansion, clutter pollution and noise influence are analyzed for better explanation. Section 4 provides the method for the finely focused image and correct relocation of moving targets. Section 5 analyzes the performance of the proposed method including the root-mean-square-error (RMSE) of the effective baseline estimation compared with the theoretical Cramer–Rao bound (CRB). Section 6 shows the performance of the proposed methods with the real SAR data. The conclusion is drawn in Section 7 with the consideration for the future work.

2. MIMO SAR signal model

Consider a dual-channel SAR working for the sidelooking mode with zero squint angle, which is shown in Fig. 1(a). We use the after antenna to transmit and two individual apertures to receive. In order to show the influence of individual squints on the effective baseline, we will give each squint formulation. Assume that the linear frequency modulation (LFM) signal is transmitted through the after channel, which can be expressed as

$$s(t) = a_r(t) \exp\left(j2\pi f_c t + j\pi \gamma t^2\right), \qquad (1)$$

where $a_r(t)$, f_c and γ denote the amplitude, carrier frequency, and chirp rate of the transmitted signal, respectively. In Fig. 1, the physical baseline length is the distance between the phase centers of two physical apertures (blue solid) and the effective baseline length is the projection of the physical baseline length on the moving track, i.e. the distance between the two projected phase centers

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