GNSS Illuminator Based High Resolution Imaging Algorithm in Space-surface Bistatic SAR

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1. INTRODUCTION

Space-surface bistatic synthetic aperture radar (SS-BSAR) consists of spaceborne illuminators and receivers mounted on or near the Earth's surface[1]. It has gained more and more researcher's interests over the past years for its benefits of getting extra forward reflective information of targets, reduced vulnerability for military applications, etc. Global navigation satellite system (GNSS) signal based SS-BSAR is a subclass of BSAR, where the GNSS satellite is used as the signal transmitter and the radar receiver could be stationary on the ground, mobile on an aircraft or on a land vehicle. It is a typical asymmetric BSAR system with non-cooperative illuminators, periodic narrowband transmitted signal, limited range resolution and low power budget.

As to its low power budget, several papers[2] have discussed deeply and some effective solutions have been proposed. In terms of image formation, because of the asymmetric configuration of SS-BSAR, many imaging algorithms[3] deal with airborne or spaceborne symmetry construction BSAR are not suitable for SS-BSAR system. Only in recent years, asymmetry BSAR image formation algorithms are studied. A modified range Doppler algorithm (RDA)[4] is proposed for SS-BSAR in the case that the transmitter and receiver have parallel flight paths and unequal velocities. Furthermore, they propose a new modified RDA image algorithm[5] for arbitrary configuration in SS-BSAR. In our previous work[6], we present a numeric bistatic range migration algorithm (RMA), specifically designed for GPS signal based SS-BSAR with arbitrary trajectory.

To achieve fine range resolution, wide-band radar signal with large time bandwidth products is needed for pulse compression. But the purpose of GNSS signal is navigation and positioning, not specially designed for SAR imaging. So it is hard to obtain high range resolution with the narrowband signal of GNSS. For example, the bandwidth of C/A code of GPS is 1.023MHz, after pulse compression based on conventional Fourier transform, the range resolution is only 150m. Such low range resolution makes it difficult to be used in imaging application. Conventional Fourier transform of pulse compression process assumes that the unavailable data samples are zero outside the window region, which is not correct in most cases and is attributed to poor resolution. As the range profile of a target consists of superposition of discrete scattering centers, the target response in the spectral domain consists of a superposition of sinusoids. With these properties, [7] presented a superresolution algorithm that can significantly improve the range resolution of processed radar return signals which is called bandwidth extrapolation(BWE). An autoregressive(AR) model was finally presented to improve the slant range resolution of pulse compression. But the improvement of resolution with BWE depended on the accurate and flexible AR modeling which is sometimes unrealistic and expensive.

A more practical approach is using conventional wide-band radars to sample the target response over a set of widely spaced subbands. In this paper, we focus on improving range resolutions of GNSS signal based SS-BSAR with the method of spectrum synthesis of ultra-band(UWB). Simulation results show that it can increase processing bandwidth and improve range resolution and target-characterization capabilities. As to the azimuth improvement of SS-BSAR system, the scattering spectrums relative to the same scene can be acquired by different antennae with spectrum shifts in azimuth direction. When join these shifted spectrums to a wider azimuth spectrum, a higher azimuth direction would be generated. A theoretical analysis of this method is given in this paper also.

2. UWB PROCESSING

A. Concept

Fig.1 illustrates the general landmark spectrum in nature. In theory, the bandwidth of electromagnetic spectrum of landmark is infinite. So we can get the infinitely high resolution of landmark. But limited by the bandwidth of radar transmitted signal, only a small part of the response spectrum can be obtained which determines the resolution of radar system. Illuminated by different radar carrier frequency, landmark spectrum of different response signal will not be the same. Assuming that two GNSS satellites illuminate signals of P code or C/A code on L1 and L2 carrier frequency respectively, synthesize the different frequency bandwidth of GNSS response signal, over-sampling the synthetic spectrum or coherently processing these subbands together makes it possible in principle to accurately estimate ultrawide-band(UWB) radar signature of target, see Fig.2.

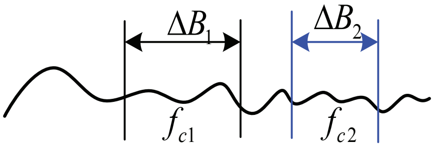


Fig. 1 Landmark spectrum

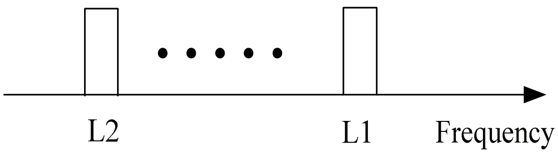


Fig.2 Frequency synthesis

B. Signal model

In order to obtain obvious synthetic bandwidth, we consider the P code of GPS with bandwidth of $10.23MHz$ modulated on carrier frequency $L_1 = 1575.42MHz$ and $L_2 = 1227.6MHz$ respectively, and assume that the structure of P code is known. As to GALILEO system, the OS QPSK signals of $10.23MHz$ on E_5 can also be used. For the GPS C/A code with $1.023MHz$ bandwidth, simulation processing is similar with lower range resolution for its low bandwidths.

The transmitted GPS signals modulated on carrier frequency L1，L2 are

$$\begin{aligned} S_{L1}(t) &= A_P P(t)\cdot D(t)\cos\omega_1 t + A_c C(t)\cdot D(t)\sin\omega_1 t \\ S_{L2}(t) &= B_P P(t)\cdot D(t)\cos\omega_2 t \end{aligned} \tag{1}$$

where, A_P 、A_C 、B_P are signal amplitudes, $P(t)$ 、$C(t)$ are P code and C/A code with values －1 or 1； $D(t)$ is the navigation data code. Response signal of point target P is

$$\begin{aligned} S_{L1}(t-\tau_1) &= A_P P(t-\tau_1)\cdot D(t-\tau_1)\cos\omega_1(t-\tau_1) \\ S_{L2}(t-\tau_2) &= B_P P(t-\tau_2)\cdot D(t-\tau_2)\cos\omega_2(t-\tau_2) \end{aligned} \tag{2}$$

where $\tau_1 = \dfrac{R_{T1}+R_R}{C}$ ， $\tau_2 = \dfrac{R_{T2}+R_R}{C}$ ，

$$\tau_1 = \tau_2 + \Delta\tau \text{ ， } \omega_1 = \omega_2 + \Delta\omega \tag{3}$$

$$S_{L1}(t-\tau_1) = A_P P(t-\tau_2-\Delta\tau)\cdot D(t-\tau_2-\Delta\tau)\cos(\omega_2+\Delta\omega)(t-\tau_2-\Delta\tau) \tag{4}$$

After frequency mixing and simplify,

$$\begin{aligned} S_{L1}(t-\tau_1) &= P(t-\tau_2-\Delta\tau)\cdot\exp\{j\Delta\omega t\} \\ S_{L2}(t-\tau_2) &= P(t-\tau_2) \end{aligned} \tag{5}$$

C. Frequency Splice and range compression

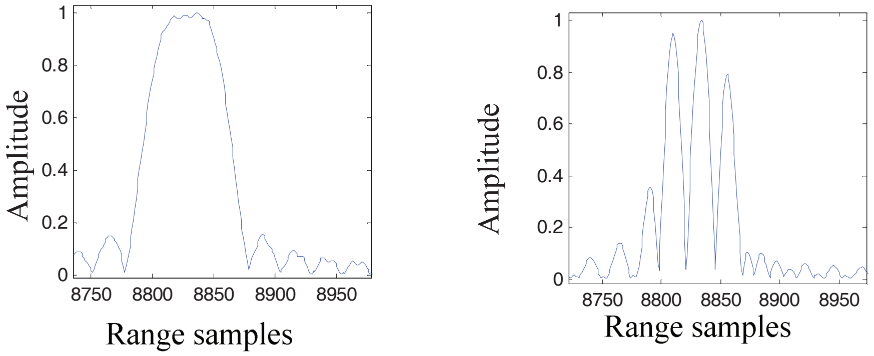
Step 1: Remove the difference of time delay $\Delta\tau$ ， $P(t-\tau_2-\Delta\tau)$----〉 $P(t-\tau_2)$。

Step 2: Spectrum synthesis

Step 3: Construct function of match filtering

$$sref_2(\omega) = \begin{cases} conj\left[P(\omega+\Delta\omega)\right] & \Delta\omega < \omega < \omega_{c2}+\Delta\omega \\ conj\left[P(\omega)\right] & 0 < \omega < \omega_{c2} \\ 0 & \omega \in others \end{cases}$$

Step 4: Range pulse compression



Signal pulse compression of L1

Signal pulse compression of L1+L2

Fig.3 Simulation results of point targets

3. SIMULATION RESULTS

3 point targets are apart from 20m each other. Only with P code signal of L1, 3 point targets can not be resolved. After spectrum synthesis of L1+L2, targets can be resolved clearly.

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