A New SAR Imaging Method for Sparse Field Target

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Abstract. Satellite borne Synthetic Aperture Radar (SAR) has become an indispensable means of earth observation because of its ability of all-weather, all-weather and global observation. However, at present, the space borne SAR still has the characteristics of large volume and high cost. In recent years, the vigorous development of micro satellite field has also promoted the research of small, intelligent and distributed cooperative imaging field of space borne SAR. The traditional spaceborne SAR imaging method is to process the echo of the received LFM signal in the two-dimensional pulse compression domain. Due to the targets in the ocean are usually sparsed, it is an effective method to detect the region of interest and targets by analyzing the echo and transform domain. In this paper, the method of azimuth pulse compression is used to realize the fast perception and imaging of sparse field targets. Through comparative analysis, it can be seen that the method has a greater improvement in resource and time consumption performance compared with the traditional method.

1. Introduction
Synthetic Aperture Radar [1] (Synthetic Aperture Radar, SAR) is widely used in all aspects of imaging in military and civilian areas due to its all-weather, all-weather, weather and light-independent effects[2-3]. At the same time, due to the large size and high cost of spaceborne synthetic aperture radars in the past, the development of spaceborne SAR has been restricted to a certain extent. Due to the limited size of the microsatellite [4-6], the signal processing load and the whole star power carried by the microsatellite platform are limited. Since the target is usually sparse in the ocean, the target usually exhibits strong scattering and has strong target characteristics. So there is a clear time-domain transition between the sea clutter in the target domain. This paper realize the perception and rapid imaging of sparse field targets by the range pulse compression method.

2. The new method to perceive the sparse target from echo data
The traditional spaceborne SAR imaging processing [7] is that the spaceborne radar transmits a linear frequency modulation (LFM) signal beam with a certain bandwidth and pulse repetition frequency to the target area. A large number of calculations are invalid processes in sparse target field. Therefore, adding the target detection process to the echo process is an effective method to improve the SAR imaging system efficiency. The new SAR imaging method is shown in Figure 1.
Figure 1. The improved SAR imaging processing in the echo domain

3. Fast perception method for sparse field target

For sparse target scenes, if the interested target could be extracted from the echo signal [8], the echo signal of the non-interest area can be filtered out automatically which will enhance the signal processing much more efficient.

3.1. Target time-domain echo model

The noise in the space is usually Gaussian-distributed white noise. Assuming that Gaussian white noise follows a statistically independent distribution with a mean of 0 and a variance of \( \sigma^2 \), the echo signal of the target area beam received by the receiver is shown in equation (1):

\[
x_n(t) = A_0 \exp(j2\pi(f_0t + \frac{1}{2}Kt^2)) + n(t)
\]  

(1)

Where \( n(t) \) is Gaussian white noise distributed in the space received by the echo.

The two-dimensional distance and azimuth echo signals received by the SAR receiver are shown in equation (2):

\[
s_0(\tau, \eta) = A_0 w_\tau(\tau - 2R(\eta)/c)w_\eta(\eta - \eta_s))
\times \exp\{j4\pi\tau R(\eta)/c\} \bullet \exp\{j\pi K(\tau - 2R(\eta)/c)^2\}
\]  

(2)

Spaceborne SAR emits beams to the target area in the azimuth direction. Since the beams emitted by the antenna have a certain beam width, usually the ground target echo will have energy distribution in multiple beams. Therefore, azimuth pulse compression is required to achieve azimuth focus and image the energy of the targets.

3.2. Target fast detection of range compression

For sparse sea targets, the received two-dimensional echo LFM matrix signal is extracted by range pulse compression to extract the energy distribution of the target in the distance direction[9]. If there is a target in the echo area, the corresponding peak in the distance position will be appeared. Otherwise, it will be recognized as a sea clutter scene. The echo signal of the target area received by the
spaceborne SAR receiver is shown in formula (2), and the range pulse compression is performed in formula (3).

\[
s_n(\tau, \eta) = IFFT_r\left\{s_0(f, \eta)H(f)\right\} = A_0pr\left[\frac{\tau - 2 \times R(\eta)}{c}\right]w_d(\eta - \eta_c) \cdot \exp\left\{-j4\pi f_0 R(\eta)/c\right\}
\]

Among them, the expression of the frequency domain matched filter \(H(f)\) is shown in equation (4).

\[
H(f) = \text{rect}\left(\frac{f}{K}\right) \exp\left\{+j\pi \frac{f^2}{K}\right\}
\]

In equation (4), \(K\) is the modulation slope of the LFM signal, and \(T\) is the pulse period of the transmitting LFM signal. The detection threshold of the distance echo target is set to \(KT\) times of the environmental noise. If the value of the compressed pulse is greater than the threshold, it is determined that there is a target. Otherwise, it is considered that there is no target in the area.

4. Simulation
The satellite orbit height is 850km, and the azimuth speed is 7.1km/s. The SAR is worked in the strip imaging mode. Meanwhile, the SNR of the received echo signal is 15dB. There are five point targets distribute in the sparse field between the range direction (9500m, 11300m) and the azimuth direction (-400m, 400m). The coordinates are shown in Table 1.

| NO. | Azimuth Coordinate/m | Range Coordinate/m |
|-----|---------------------|-------------------|
| 1   | -100                | 9700              |
| 2   | -50                 | 10200             |
| 3   | 10                  | 10380             |
| 4   | 30                  | 10460             |
| 5   | 90                  | 10750             |

The method for rapid detection of range-based targets is to perform range pulse compression processing on the received range and azimuth two-dimensional signals first. The three-dimensional energy distribution diagram is shown in (a) and (b) on Figure 2.

(a) Three-dimensional perspective view of range pulse compression  
(b) Range pulse compression Range angle view

Figure 2. Schematic diagram of range pulse compression
The condition for further imaging process is determined by the peak result of the range pulse compression. If there are some interested targets in the area, then the remaining signal processing will be executed about these area echo data[10]. Otherwise, the raw echo signal will be ignored so as to achieve the maximum utilization of the resources. The imaging result of SAR sparse targets based on RDA algorithm after RCMC is shown in Figures 3.

The energy of the targets will be focused by the range pulse compression. Since the number of the targets in the ocean are sparse, how to save the energy and the computing source is much more important for the platform. We set the experiment that the targets are appeared in the sparse field randomly. Through 1000 times monte-carlo simulations of sparse field about the randomly targets, the average resource consumption and the average computing time are tested separately with the traditional method and the new method proposed in the paper.

Since the traditional SAR imaging method don’t have the ability to perceive the effective targets in the raw echo signal, the most resource are waste which there are no effective targets in the echo. Compared with the average energy consumption of traditional method, it has a 37.8% reduced in the new method which much more invalid raw echo signals are automatically removed. In addition, the average calculation time also saves 43.7% in the new method.

5. Summary
The sparse field target detection and imaging method of spaceborne SAR based on range pulse compression proposed in this paper can greatly improve the efficiency of the system. The traditional spaceborne SAR imaging method couldn’t perceive the interested targets from the raw echo data which could greatly reduce the source and improve the SAR imaging efficiency particularly. It also reflects the intelligence of the SAR processing for fast ROI targets imaging.

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