A Sparsity Enhancement Algorithm of Echo Signal for Wide Area Multi-target Imaging

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Abstract: Sparse distributed large array radar can detect wide area through wide beam, and can explore and image multiple targets in wide area at the same time. However, after the matched filtering in range profile, motion trajectories are different because of different motion parameters of each target. And some problems such as defocus may occur if the imaging is carried out directly. Therefore, according to the line detection method of Radon transform, the echo signal is processed to enhance the sparsity in the range profile, and the echo signal is separated into multiple single target echo signals. First of all, the range image is interpolated or downsampled to make the two-dimensional size balanced; secondly, the image is segmented along the azimuth direction and detected in segments. Each track of each target is fitted in a line; and finally, each line is spliced together to construct the mask of each signal and separate the signal of each target.

1. Introduction

The sparse distributed large-array radar for wide-area detection can detect air through a wide beam, while receiving all the target echoes wide-area scope. Compared with the traditional narrow-beam-to-air imaging radar, it overcomes the inability of narrow-beam detection in simultaneous detection and imaging of targets in multiple areas. And it avoids defocusing since there is no need for the target to be cooperative during movement. It is of great significance to realize wide-area full-time space detection and image multiple targets at the same time. The sparse characteristics of the wide-area echo signal can be used for imaging. Before imaging, echo signals containing multi-target information can be further separated into multiple single-target echo signals by means of different signal sparsity enhancement, so that the subsequent imaging process can better apply the signal sparsity.

In this paper, a method to enhance the sparseness of the wide-area multi-target echo signal from the range profile is proposed. According to motion trajectories of multiple targets in the range profile over a period of time are different, the motion trajectory of each target is fitted with the corresponding straight line based on the Radon transform, and then the signal in the range profile are masked. In order to get better separation results, the signal is processed by segmental processing before Radon transform.

2. Problem Formulation

2.1. Echo Signal Model

Suppose that the radar system is uniformly distributed and square. Each row and each column are composed of the same number of array elements, and the distance between the rows and columns is equal. The established geometric model is shown in Figure 1.

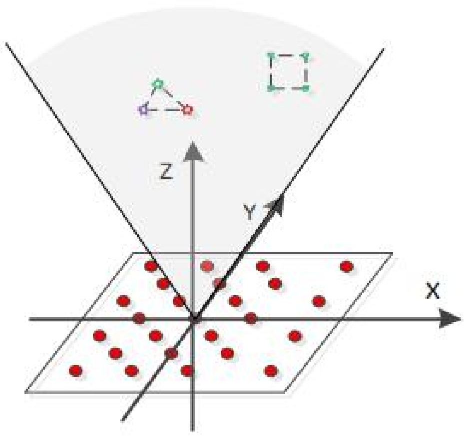


Figure 1: Geometric model of sparse distributed large-array radar.

The array plane is parallel to the horizontal plane, with the center array element as the origin of the coordinate system, and the array plane as the zero height plane. Each target moves in space at a fixed speed. The center frequency and bandwidth of the chirp signal transmitted are respectively f_0 and B ,and the echo received by each array element can be expressed as:

$$S_r(t)=\sum_{j=1}^{M}\sum_{i=1}^{N}\sigma_j(i)\exp\left\{j2\pi\left[f_0(t-\frac{2R_j}{C})+\frac{1}{2}\frac{B}{T}(t-\frac{2R_j}{C})^2\right]\right\} \quad (1)$$

Where i is the number of reflection points of each target, j is the number of targets. $_j(i)$is the reflection coefficient of each reflection point and R_j is the distance from the array element to the reflection point.

2.2. Multi-target Echo Imaging

After range pulse compression, the echo can be compressed in azimuth by certain pulses accumulation. However, the echo obtained from wide-area detection by wide-beam radar contains multiple target information. And the motion parameters of each target are different result in the relative motion of the array elements is not consistent. So it is impossible to obtain high quality multi-target imaging if the azimuth compression is carried out directly, as shown by Figure 2. If the unified correction compression of the azimuth dimension is carried out directly according to a certain compensation criterion, the goal can not be achieved because of the range profiles of targets varying too much.

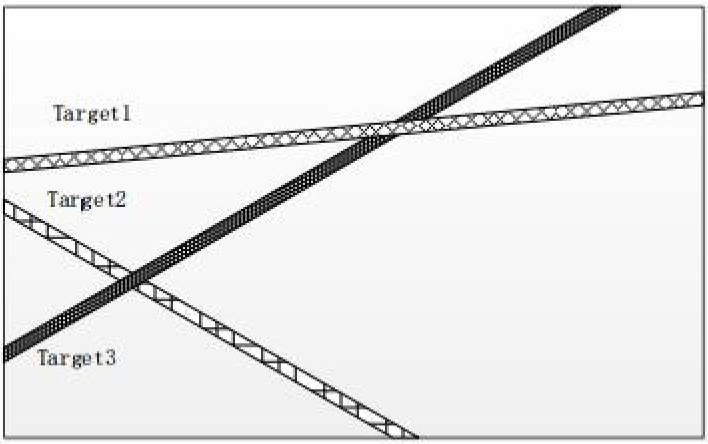


Figure 2: Different targets have different trajectories.

For echo imaging with multi-target information, the most intuitive and effective method is to analyze and image each target separately. Therefore, in order to realize the imaging of multi-target echoes and make better use of the sparse characteristics of wide-area echo signals, the sparsity of echoes is enhanced from the range profile by separating the echoes containing multi-target information into multiple echoes containing only single target information. Through line detection, the slope of the line is estimated and the mask is constructed, the range profiles of each target are separated one by one, and then the echoes of each target are processed separately.

3. Signal Sparsity Enhancement in Range Profile

3.1. Interpolation/Resolution Reduction

After a period of pulse accumulation and range matching filtering of the echo of each pulse, the trajectory of each target on the range profile can be obtained. Before line detection, the size of the image needs to be considered. In the range dimension, because the sampling frequency is very high, there will be more sampling points, while in the azimuth dimension, only dozens of pulses are needed to see the trajectory of the target. If the straight line detection is done directly, the size difference between the two dimensions of the image lead to the wrong straight line detection results.

Therefore, before line detection, it is necessary to interpolate the image in the azimuth dimension, or reduce the resolution in the distance direction, so that the two-dimensional size of the image is balanced and the straight line detection can be carried out normally.

Resolution Reduction. After the matched filtering in the frequency domain, reducing the number of points of the inverse Fourier transform will reduce the resolution of the image in the distance dimension, but it can reduce the number of points in the range dimension of the image, so that there is little difference between the size of the image in the range dimension and the azimuth dimension, making it easy to do straight line detection.

Interpolation. In order to match the amount of two-dimensional data of the image, the azimuth dimension can also be interpolated so that the number of azimuth dimensions of the image is equal to the number of points in the range dimension. When interpolating, we do two-dimensional linear interpolation to the image, as shown in Figure 3.

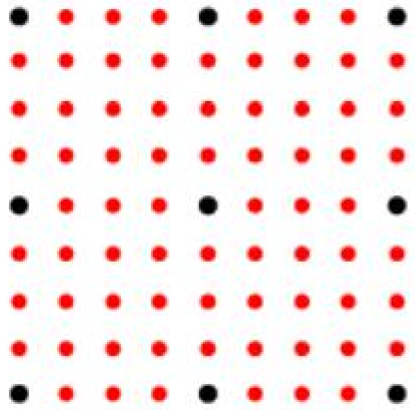


Figure 3: Schematic diagram of two-dimensional linear interpolation, in which the values in the original matrix are black dots and remain unchanged, and linear interpolation is carried out between the original data.

After interpolation or resolution reduction, the points of azimuth and range dimension become balanced. The interpolated image can be used for straight line detection to separate the echoes of different targets.

3.2. Segments

Since the movement of the target may not move at a constant speed in the radial direction of the radar, the trajectory of the target may be a curve instead of an ideal line. Therefore, in this process, the straight line detection result of the target trajectory may have a large error. To make the result fit the curve more closely. We fit the curve trajectory in sections, divide the azimuth dimension into several small sections of equal length, and perform straight line detection separately. And the target trajectory in each segment is approximated as a straight line.

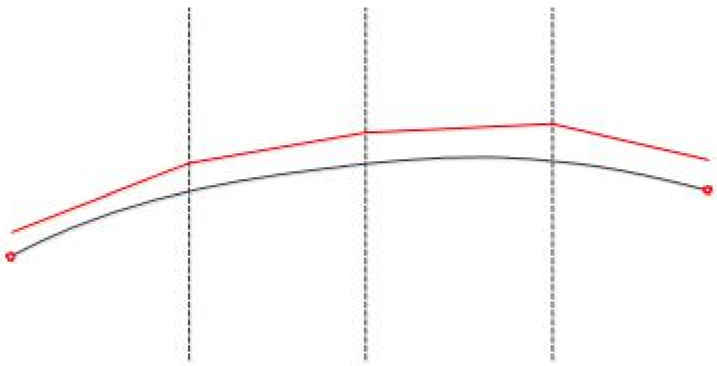
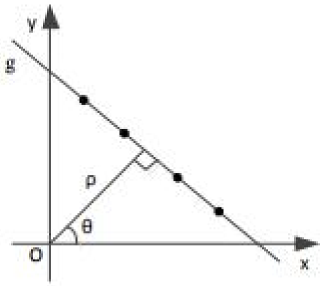


Figure 4: Piecewise fitting trajectory.

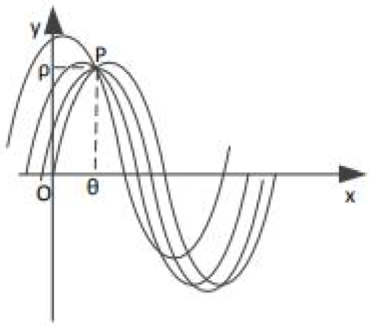
3.3. Separation

After the trajectory of each target is segmented, the linear detection is performed on each trajectory in each segment to estimate the different slope and intercept, and the target image of each segment is separated. Radon transform can detect different lines in the image. The main idea is to convert the line detection in the image space into the point detection in the parameter space. The points on the same line will be accumulated at the same position after converted to the parameter space. and finally peak statistics appear. And those peaks are lines which we detect in space. The transformation equation is as follows:

$$\rho = x\cos\theta + y\sin\theta,\ \rho \geq 0, 0 \leq \theta \leq \pi \tag{2}$$



(a)



(b)

Figure 5: Radon transform diagram, wire duality principle.

4. Experiment and Analysis

In this section, numerical simulations are conducted to validate the proposed method. Total 625 array elements are distributed equally spaced as a square array of which both sides are 900m long. The signal bandwidth is 100MHz. The central frequency is 2GHz and the PRF is 100KHz. The distribution is as shown by Figure 6 Given the initial position and velocity, the observation height is 8km/10km, The azimuth beam width is 32degrees. Observe the scene as shown in Figure 7:

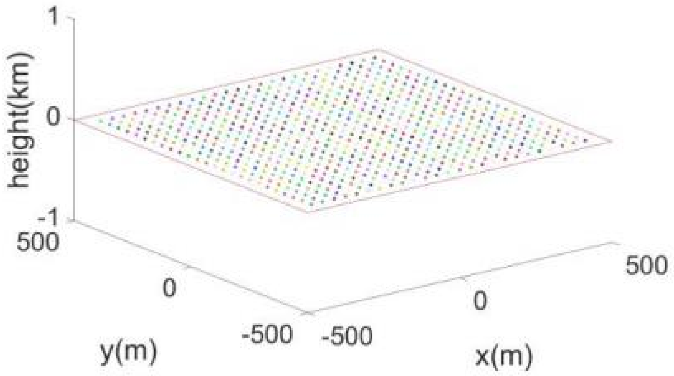


Figure 6: Array configuration.

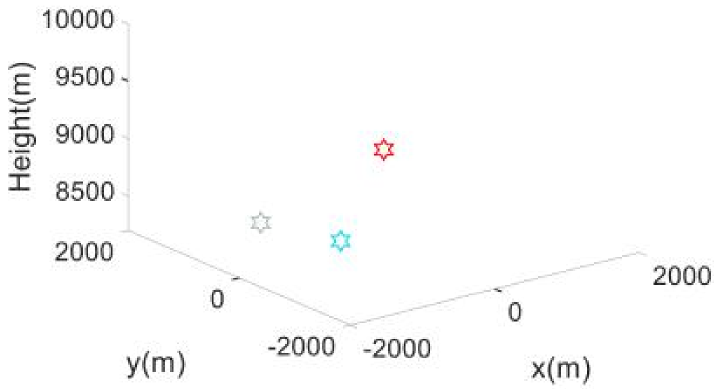


Figure 7: Scene of the target.

The range pulse compression of the echo is carried out, and observe the moving track of each target in the distance dimension in 60 pulse times of one array element (the central array element), as shown in Figure 8.

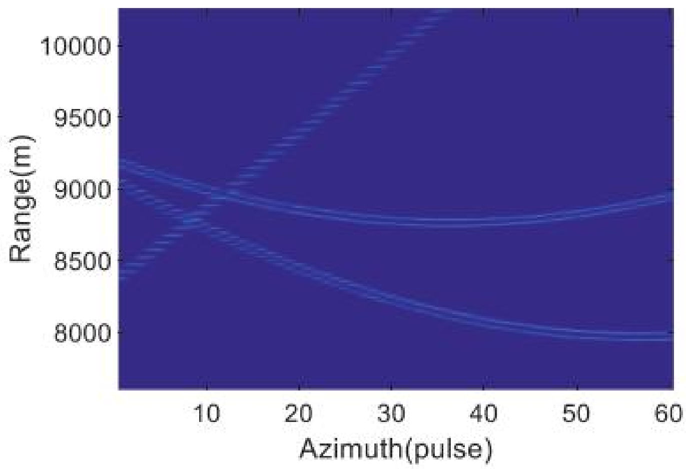
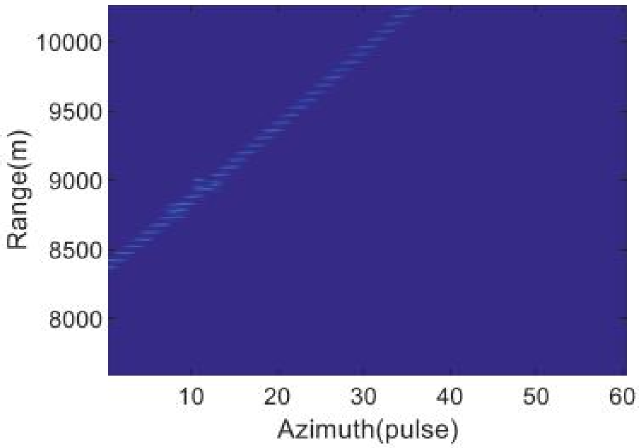
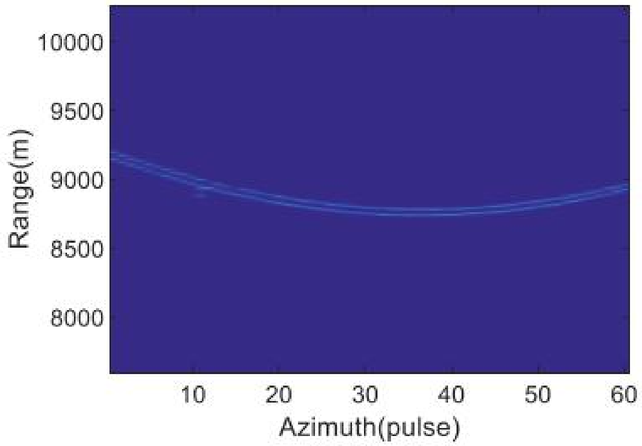


Figure 8: Different trajectories in 60 pulses.

Before dividing the image into four segments along the azimuth dimension, two-dimensional interpolation is performed to make the number of points equal in two-dimensional direction of each segment, then Radon transform is performed to find peaks in the parameter domain. After that, Radon inverse transform is performed to obtain the linear mask of each target track. Finally, each track of each target is spliced together to obtain the echo signal of a single target. As shown in Figure 9,



(a)



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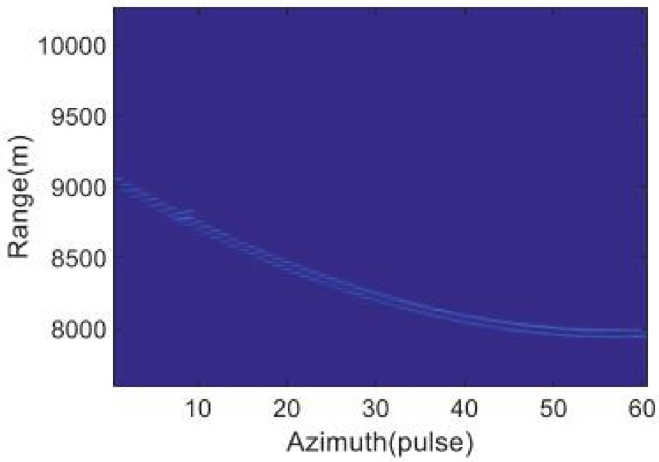

(c)

Figure 9: Sparsity enhancement results.

According to this algorithm, the echoes of the three targets can be effectively separated and the sparsity of the echo signal can be enhanced.

5. Conclusions

The echo of wide-area detection by wide-beam radar contains a lot of target information. This algorithm can effectively separate multiple targets with different motion parameters, and achieve the purpose of enhancing signal sparsity. In the next step of work, we will discuss the similarities and difference of processing echo signals under other form of radar array conditions.

Acknowledgments

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