ESTIMATION EFFICIENCY, ACCURACY AND ROBUSTNESS IMPROVEMENT BY EXPLOITING THE GEOMETRY INFORMATION IN RADAR MOVING TARGETS DETECTION AND IMAGING

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Suffering from ambiguous estimation or heavy computation complexity load, the radial velocity estimation of moving targets becomes the bottleneck of the synthetic aperture radar-ground moving target indication system. In order to improve the radial velocity estimation efficiency, we have proposed an efficient Radon transform (RT) estimation (ERTE) method by using the never exploited geometry information, which performs well in high SNR scenarios but bad for low SNR. Focusing on these, we propose the least square RT estimation (LSRTE) method to improve the estimation accuracy by utilizing the geometry information of multiple RT results. Given the geometry information determining measurement error, we modified the LSRTE into a weighted LSRTE (WLSRTE) method to improve the estimation robustness and accuracy. Experiments results validate the effectiveness of the proposed methods, and the proposed methods perform much more accurate and efficient than the conventional method.

By exploiting the geometry information, the estimation performance (efficiency, accuracy and robustness) can be improved. The concept of the methods can be used in the parameters estimation field, especially .

Key words: Parameters Estimation; Estimation Performance Improvement; Geometry information; Efficiency; Robustness

Parameters Estimation Efficiency and Accuracy Improvement

The basic methods

Radial velocity can be estimated by range walk angle

$$v_r = c \cdot \tan\theta \cdot PRF / 2f_s$$

And then the radial velocity estimation turns to angle estimation. Conventionally, the range walk angle is searched by the Radon transform with low efficiency, as shown in Fig.1(a).

By analyzing the projection nature of Radon transform, we can obtain the geometry relationship between the Radon transform results and the range walk angle

$$L_\theta \left|\cos\left(\theta + \left(90^\circ - \varphi\right)\right)\right| = L_\varphi$$

Since the limited radial velocity brings limited range walk angle, and the absolute operation can be removed. And two Radon transform results can be written by

$$L_\theta \sin(\alpha - \theta) = L_\alpha$$
$$L_\theta \sin(\theta - \beta) = L_\beta$$

And the range walk angle can be estimated by using the formulas above as

$$\tan\hat{\theta} = \frac{L_\beta \sin\alpha + L_\alpha \sin\beta}{L_\beta \cos\alpha + L_\alpha \cos\beta}$$

And then the radial velocity of moving target can be obtained as

$$\hat{v}_{r,ERT} = \frac{c \cdot PRF}{2f_s} \frac{L_\beta \sin\alpha + L_\alpha \sin\beta}{L_\beta \cos\alpha + L_\alpha \cos\beta}$$

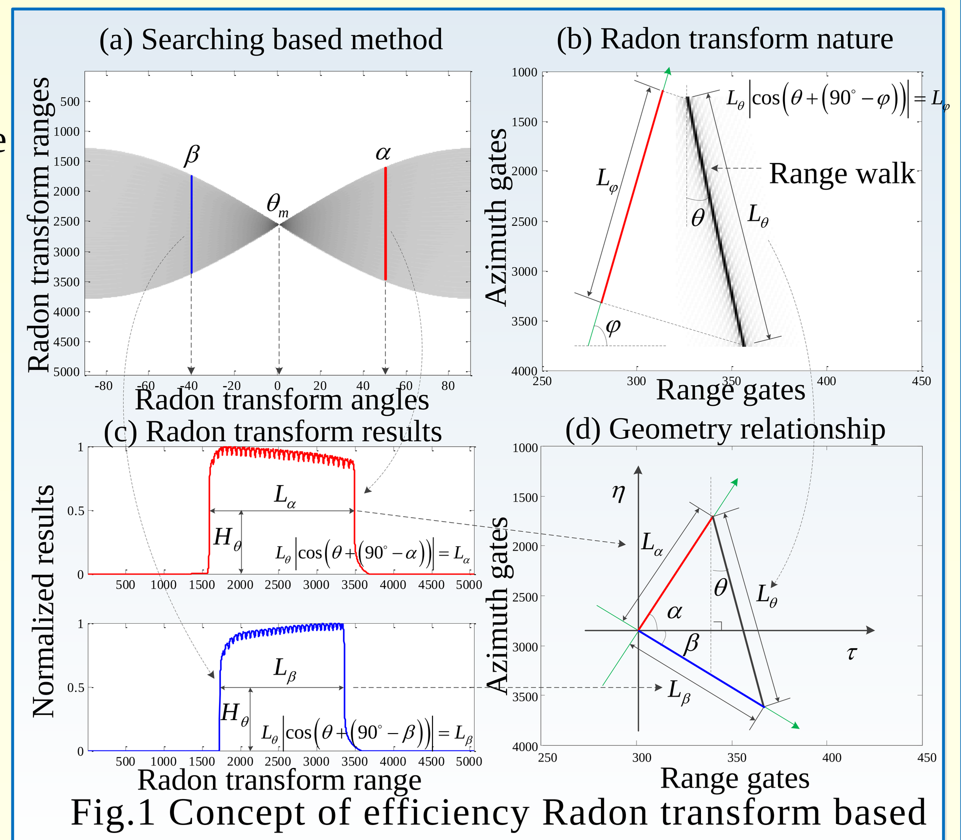

Fig.1 Concept of efficiency Radon transform based estimation method.

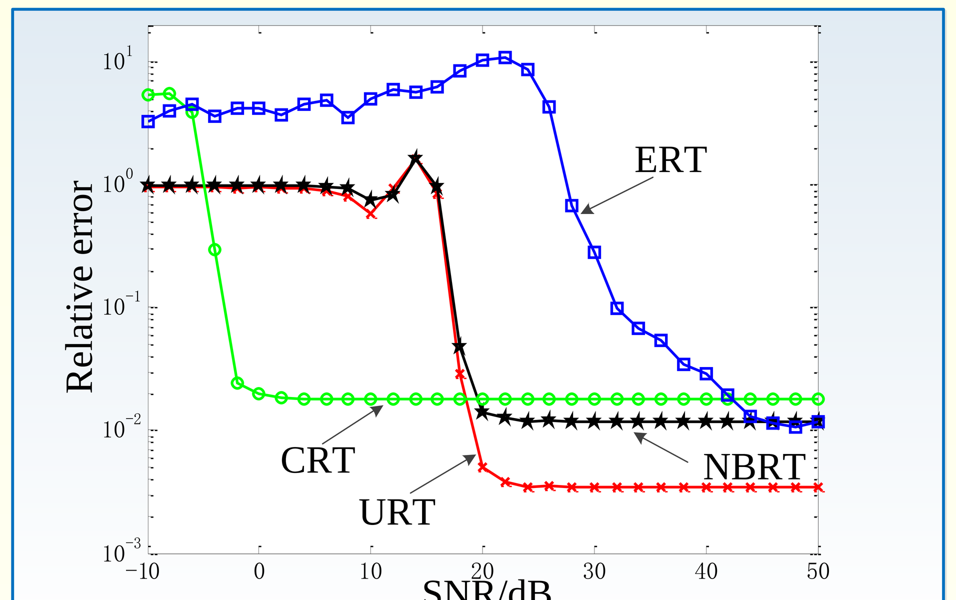

Fig.2 Estimation performance comparison versus SNR.

Clutter and Noise background

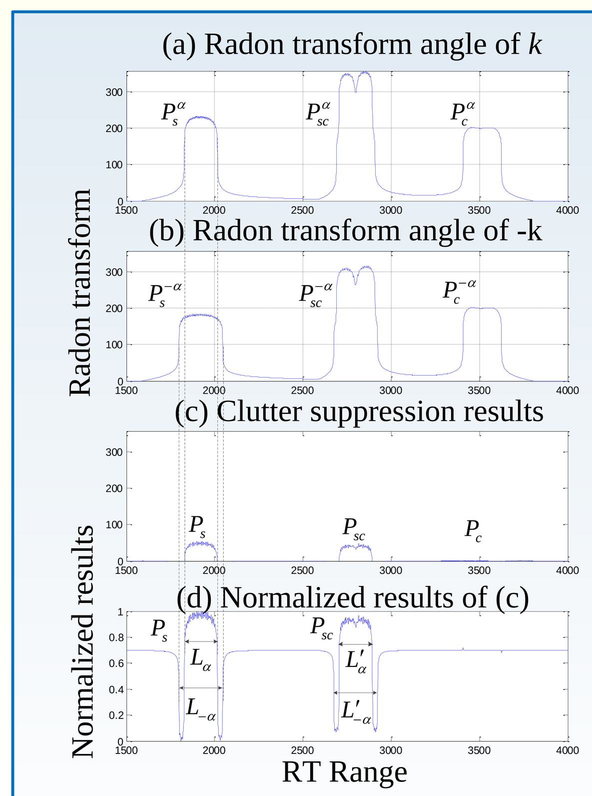

Fig.3 Radon transform used for clutter suppression.

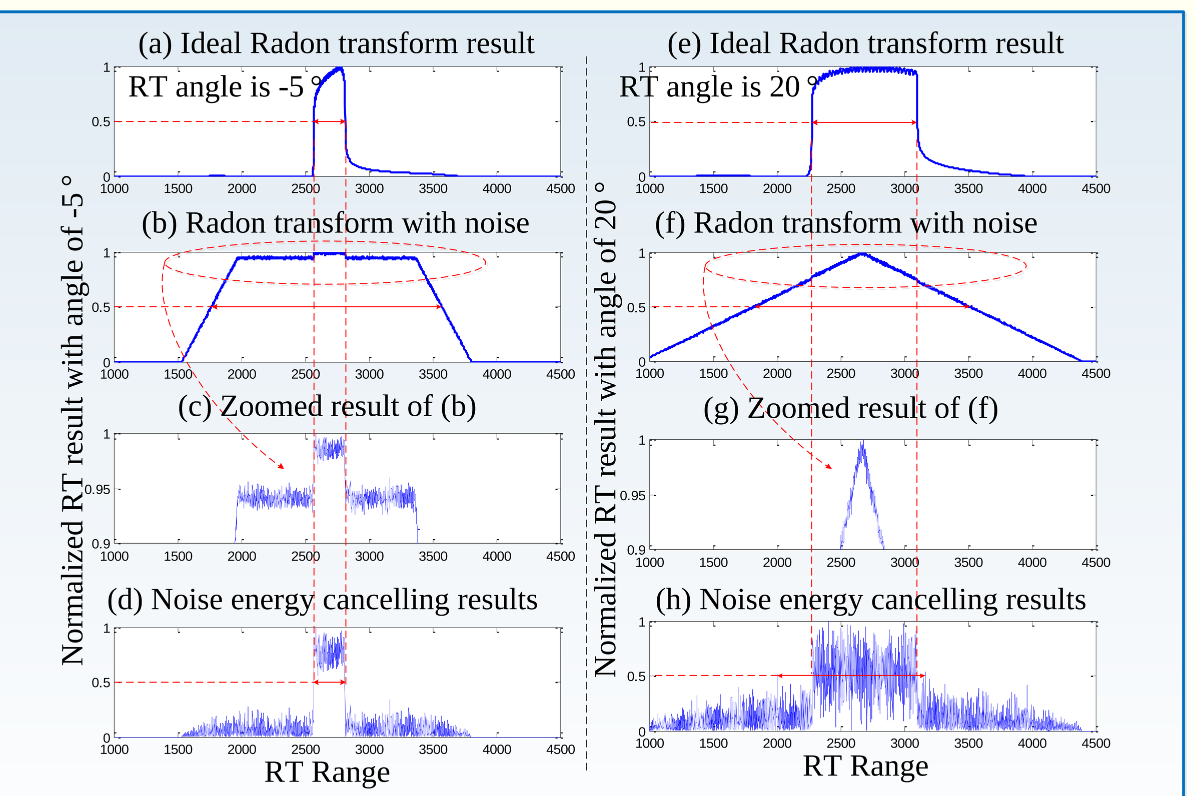

Fig.4 Radon transform used for noise energy cancelling.

Parameters Estimation Robustness Improvement

The multiple transforms method

To improve the robustness further, we modified the geometry model as

$$L_\theta \sin(\theta - \alpha) + \varepsilon = L_l$$

which can be expanded as

$$L_\theta (\cos\alpha \quad -\sin\alpha)(\sin\theta \quad \cos\theta)^T + \varepsilon = L_l$$

Multiple Radon transform results, i.e.

$$\begin{pmatrix} \cos\alpha_1 & -\sin\alpha_1 \\ \cos\alpha_2 & -\sin\alpha_2 \\ \vdots & \vdots \\ \cos\alpha_N & -\sin\alpha_N \end{pmatrix} \begin{pmatrix} L_\theta \sin\theta \\ L_\theta \cos\theta \end{pmatrix} + \begin{pmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_N \end{pmatrix} = \begin{pmatrix} L_1 \\ L_2 \\ \vdots \\ L_N \end{pmatrix}$$

And its matrix form can be written as

$$\mathbf{Ax + e = L}$$

By using the least squared method, the range walk angle can be estimated by

$$\left[L_\theta \sin\theta \quad L_\theta \cos\theta\right]^T = \hat{x} = \left[A^T A\right]^{-1} \cdot A^T L$$

and $\tan\theta = L_\theta \sin\theta / L_\theta \cos\theta = \sin\theta / \cos\theta$

And then the radial velocity can be obtained.

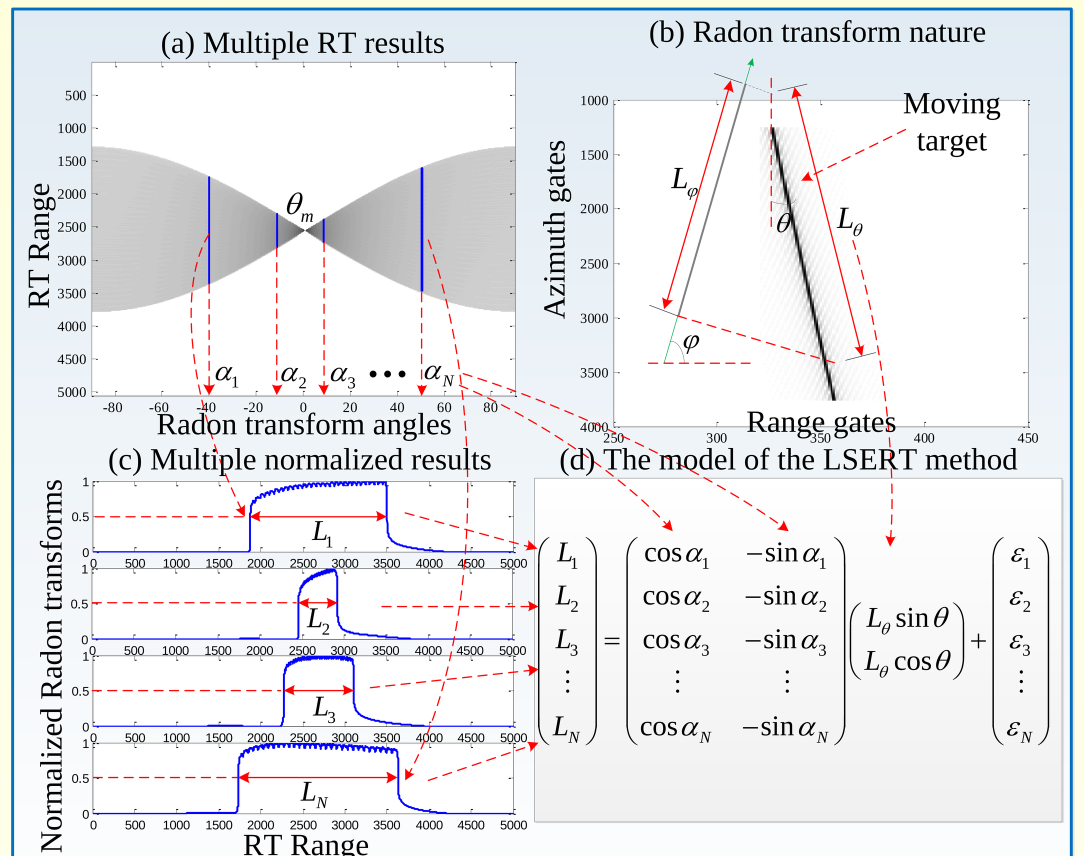

Fig.5 Concept of robust Radon transform based estimation method.

The weighted method

To improve the robustness further, we modified the geometry model as $Ax + Ke = L$

Geometry information is used to weight the error

$$Ax + \frac{G}{\eta_{RC} L_\theta}\left[diag(Ax)\right]e = L$$

And the angle can be estimated by the weighted least squared method

$$\left[L_\theta \sin\theta \quad L_\theta \cos\theta\right]^T = \left[A^T W^{-2} A\right]^{-1} \cdot A^T W^{-2} L, \quad W = diag(L)$$

Estimation performance comparison

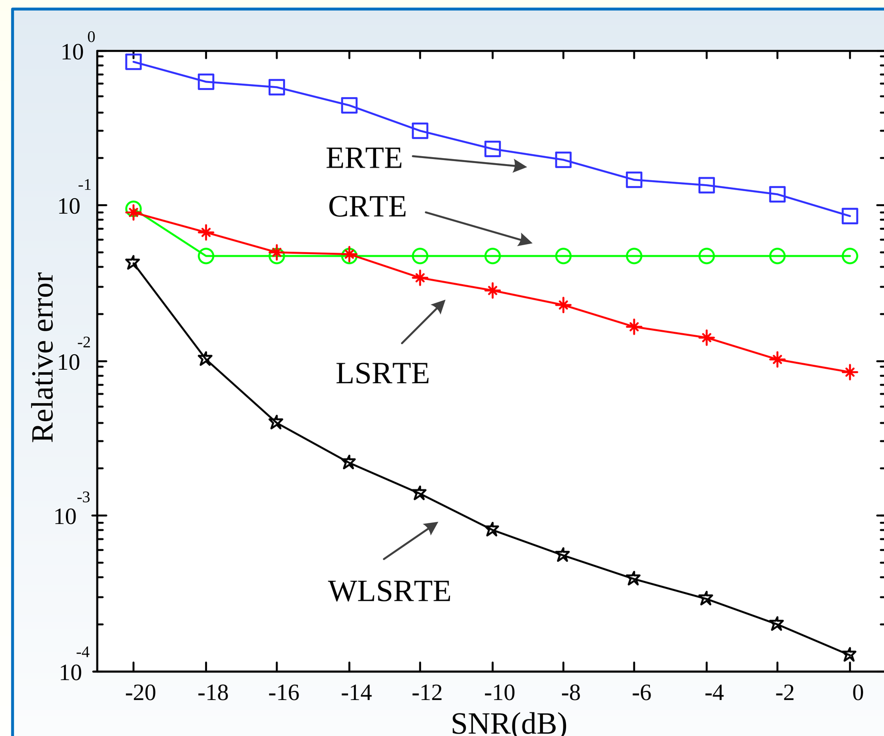

Fig.6 Estimation robustness comparison versus SNR.

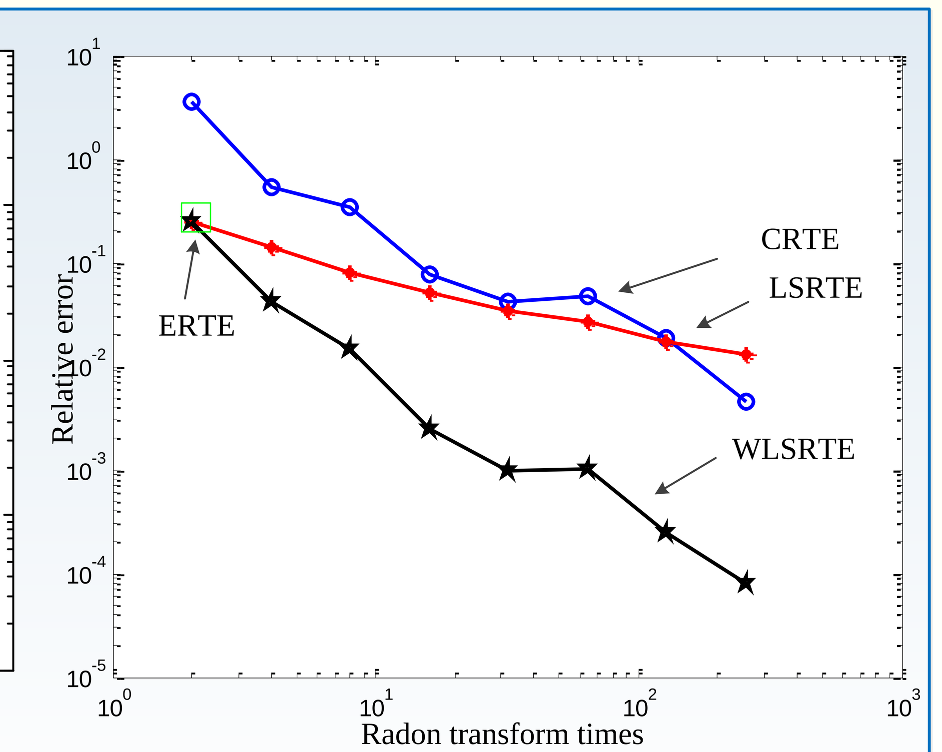

Fig.7 Estimation accuracy comparison versus computing time.

Real Data Processing Results

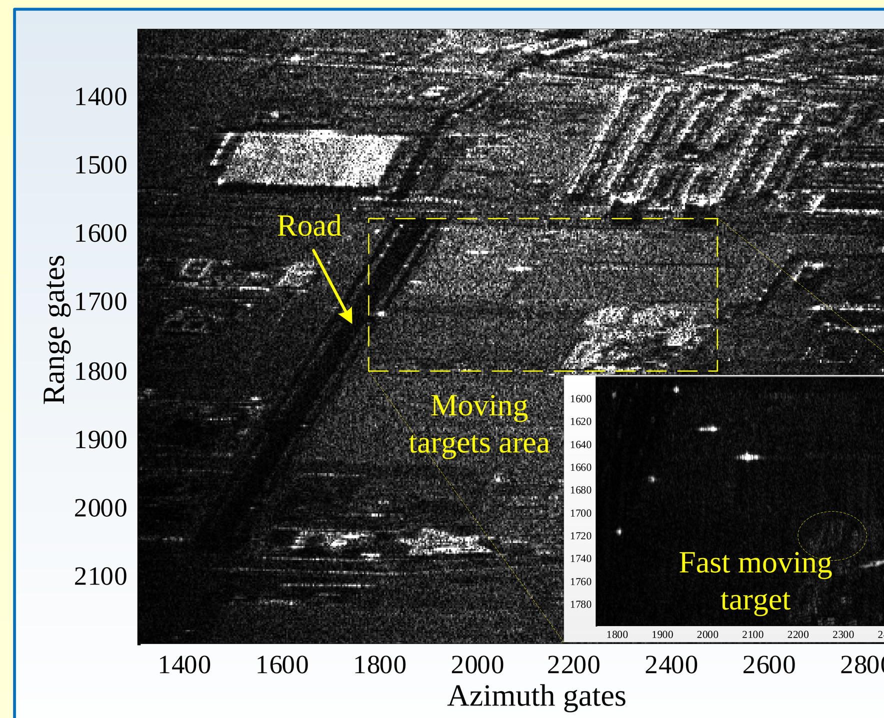

Fig.8 SAR and moving targets detection results.

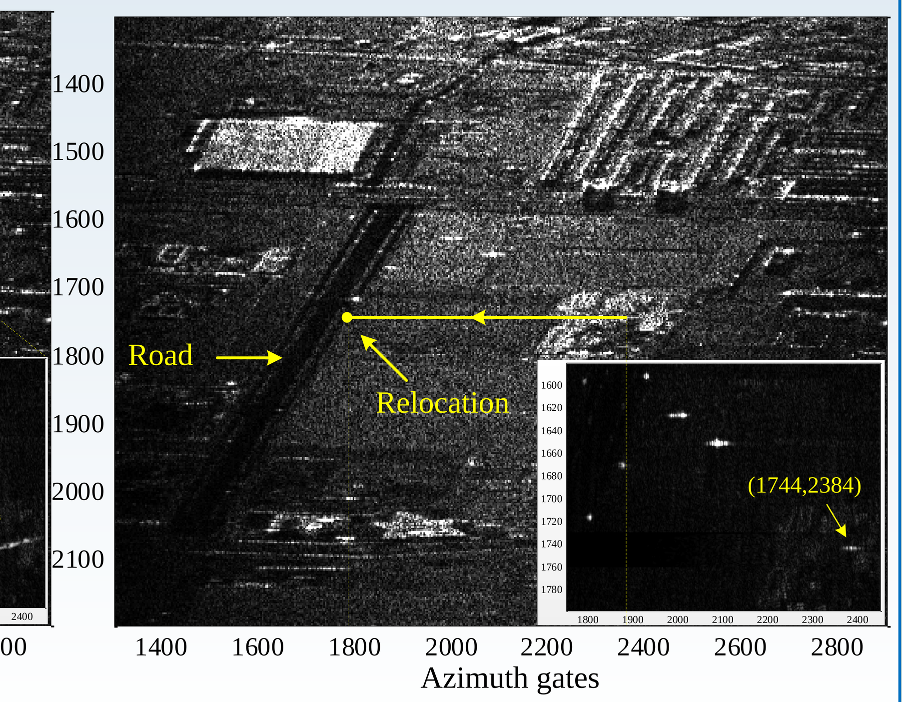

Fig.9 Moving target imaging and localization results.

Other Applications

Doppler Rate Efficient Estimation

Geometry information can also be used such as efficient Doppler rate estimation.

By analyzing the nature of WVD, the edge of the searching based results can be parameterized as

$$f(\phi) = \left|C_1 \sin(\phi - \vartheta) + C_0\right|$$

The Doppler rate can be estimated by

$$\hat{\gamma}_a = -\frac{f_{sa}\left(L_\alpha \cos\beta + L_\beta \cos\alpha\right)}{T_a\left(L_\alpha \sin\beta + L_\beta \sin\alpha\right)}$$

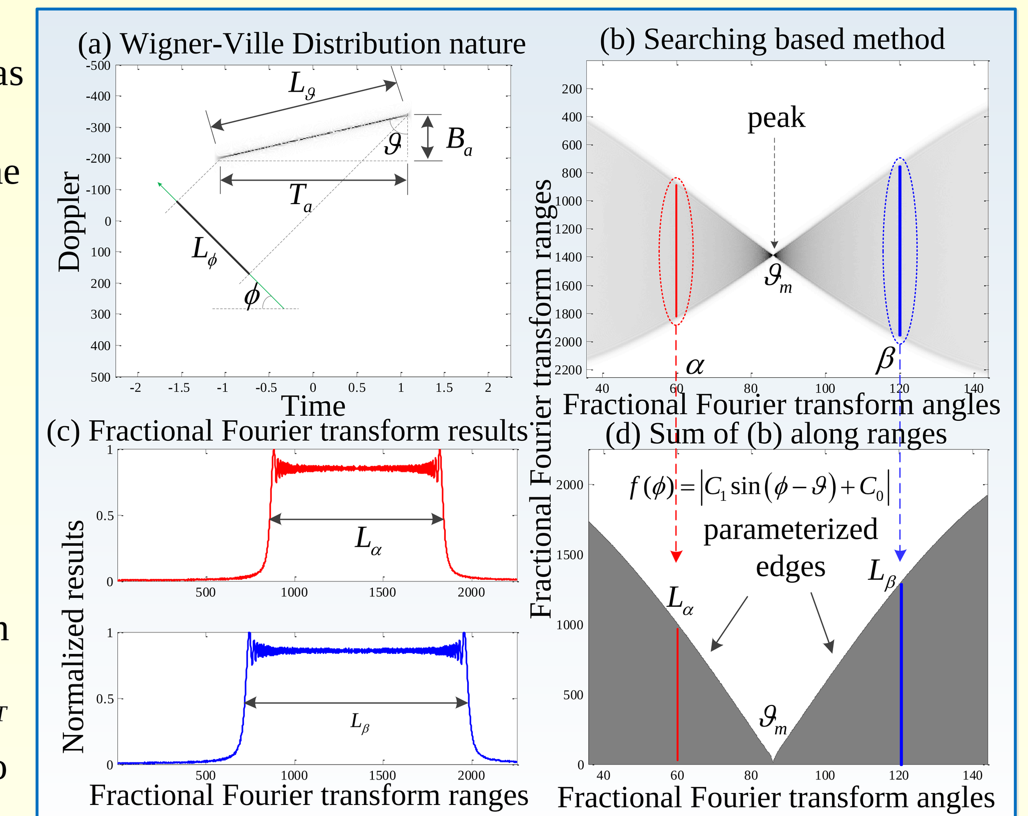

Fig.10 Concept of efficient compressed sensing method.

Efficient Sparse Imaging

This can be further used for sparse imaging.

The compressed sensing model can be written by the discrete fractional Fourier transform as

$$y = \Phi x + \varepsilon = \Phi \cdot \left(F^{2\varphi/\pi}\right)^T \theta + \varepsilon, F^{2\varphi/\pi} = VD^{2\varphi/\pi}V^T$$

And the geometry information of the two recovery results

$$\hat{\theta}_\alpha = \arg\min \|\theta\|_1, \quad s.t. \left\|y - \Phi\left(F^{2\alpha/\pi}\right)^T \theta\right\| \le \varepsilon$$
$$\hat{\theta}_\beta = \arg\min \|\theta\|_1, \quad s.t. \left\|y - \Phi\left(F^{2\beta/\pi}\right)^T \theta\right\| \le \varepsilon$$

are used for moving targets efficient sparse imaging by $\hat{\theta}_{\hat{\vartheta}} = \arg\min \|\theta\|_1, \quad s.t. \left\|y - \Phi\left(F^{2\hat{\vartheta}/\pi}\right)^T \theta\right\| \le \varepsilon$

Real Data Processing Results

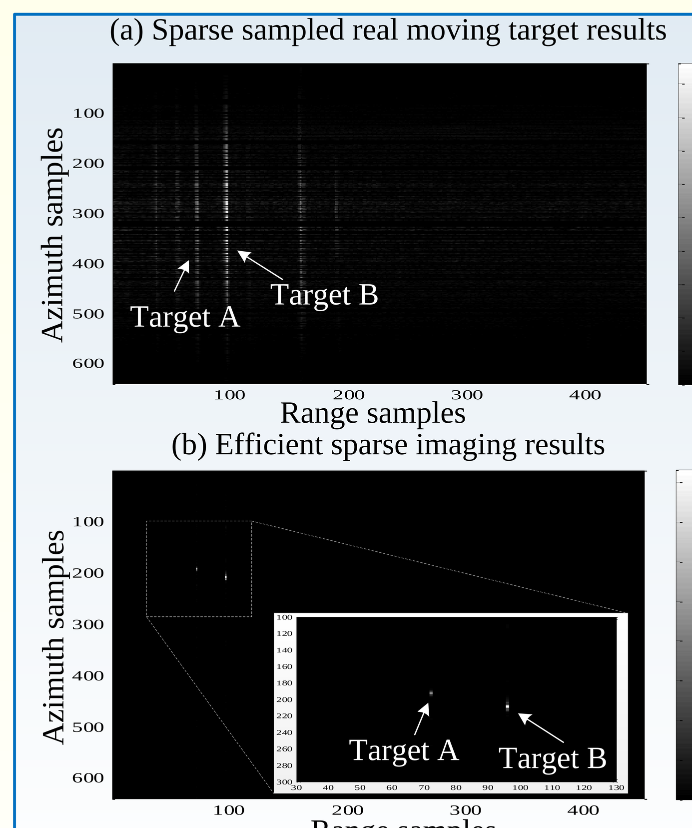

Fig.11 Real data processing.

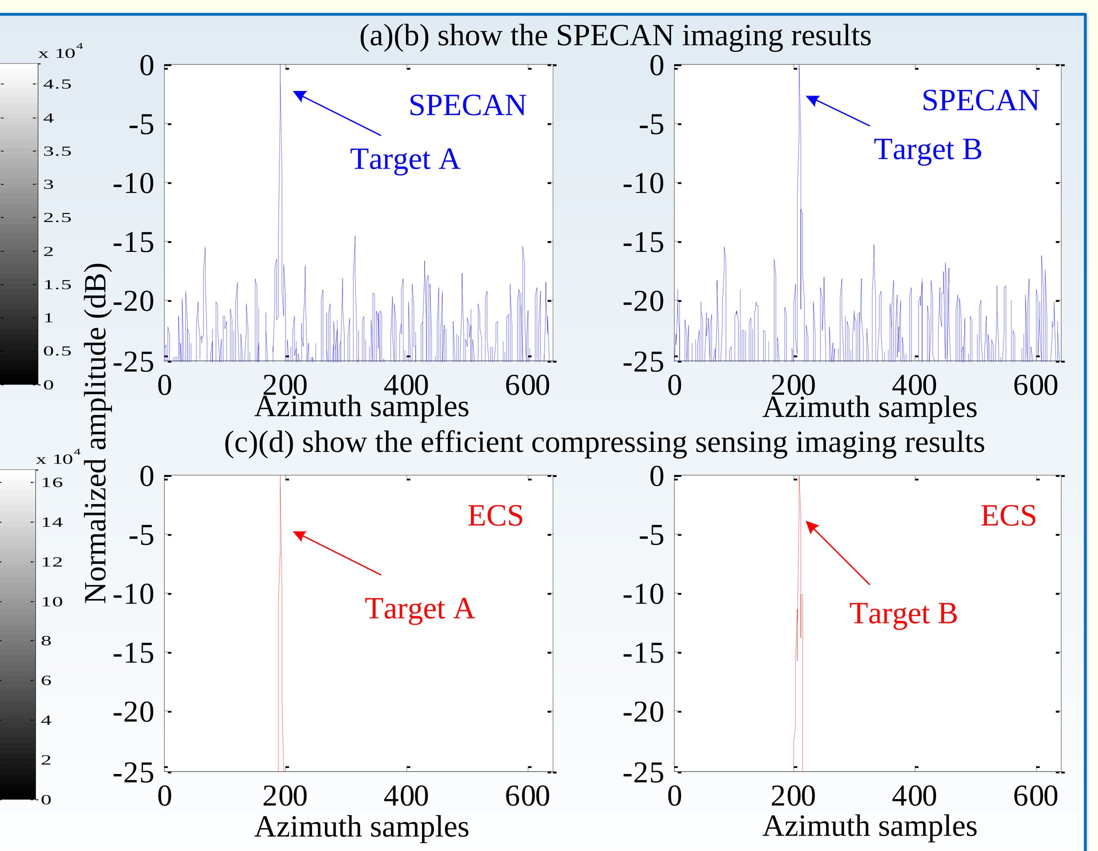

Fig.12 Imaging results comparison.

Related Publications

[1] Xuepan Zhang, Guisheng Liao, Shengqi Zhu, Cao Zeng, Yuxiang Shu. Geometry Information Aided Efficient Radial Velocity Estimation for Moving Targets Imaging and Location Based on Radon Transform. IEEE Transactions on Geoscience and Remote Sensing. 2015, 53(2):1105-1117.

[2] Xuepan Zhang, Guisheng Liao, Shengqi Zhu, Yongchan Gao, Jingwei Xu. Geometry Information Aided Efficient Motion Parameters Estimation for Moving Targets Imaging and Location. IEEE Geoscience and Remote Sensing Letters. 2015, 12(1): 155-159.

[3] Xuepan Zhang, Guisheng Liao, Shengqi Zhu, Dong Yang, Wentao Du. Efficient compressed sensing method for moving targets imaging by exploiting the geometry information of the defocused results. IEEE Geoscience and Remote Sensing Letters. 2015, 12(3): 517-521.