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Efficient coherent detection of maneuvering targets based on location rotation transform and non-uniform fast Fourier transform

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Key words: Coherent integration; Maneuvering target; Parameter estimation; Location rotation transform; Non-uniform fast Fourier transform

Corresponding author: Ke JIN
E-mail: jinke_xd@outlook.com
ORCID: https://orcid.org/0000-0003-4666-565X

Motivation

- Long-term coherent integration can remarkably improve radar's detection ability for maneuvering targets. However, the linear range migration, quadratic range migration, and Doppler frequency migration seriously degrade the detection performance.
- Traditional linear integration methods obtain satisfactory anti-noise performance at the expense of computational efficiency. At the same time, cross-terms interference and performance loss cannot be avoided in nonlinear methods.

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Main idea

- The second-order keystone transform is firstly adopted to eliminate the quadratic range migration.
- The linear frequency migration can be corrected using the location rotation transform. The velocity is estimated from the rotation angle and the linear phase term is accordingly compensated for.
- The Doppler frequency migration is efficiently eliminated via the non-uniform fast Fourier transform.

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Method

1. Second-order keystone transform

$$S(f_r, t_m) = A_f \ \mathrm{rect}\left(\frac{f_r}{B}\right)\exp\left(-\mathrm{j}4\pi f_r \frac{N_b v_b t_m}{c}\right)$$
$$\cdot \exp\left[-\mathrm{j}4\pi(f_r + f_c)\frac{R_0 + v_0 t_m + 0.5 a t_m^2}{c}\right]$$

$$t_m = \left(\frac{f_c}{f_r + f_c}\right)^{1/2} t_a$$

Second-order keystone transform

$$S_{\mathrm{SoKT}}(f_r, t_a) = A_f \ \mathrm{rect}\left(\frac{f_r}{B}\right)\exp\left(-\mathrm{j}4\pi f_r \frac{R_0 + V_e t_a}{c}\right)$$
$$\cdot \exp\left(-\mathrm{j}4\pi \frac{R_0 + v_0 t_a + 0.5 a t_a^2}{\lambda}\right)$$

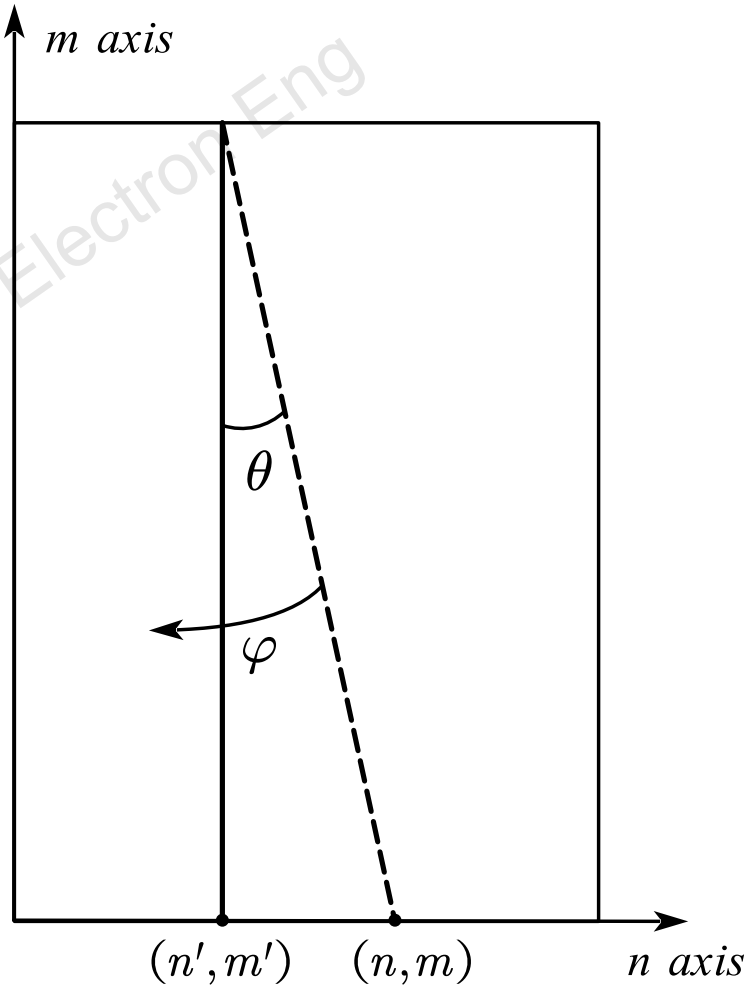
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2. Location rotation transform

$$s_{\mathrm{SoKT}}(n,m)=A_{\mathrm{c}}\,\mathrm{sinc}\left[\frac{1}{K}\left(n-n_{R_0}\right)-\frac{1}{\Delta r}V_{\mathrm{e}}mT\right]\cdot\exp\left(-\mathrm{j}2\pi\frac{c}{\lambda KB}n_{R_0}\right)\exp\left(-\mathrm{j}\frac{4\pi}{\lambda}v_0mT\right)\cdot\exp\left[-\mathrm{j}\frac{2\pi}{\lambda}a(mT)^2\right]$$

$$\begin{bmatrix}m\\n\end{bmatrix}=\begin{bmatrix}1&0\\\tan\varphi&1\end{bmatrix}\times\begin{bmatrix}m'\\n'\end{bmatrix}$$

$$s_{\mathrm{rot}}(n',m')=A_{\mathrm{c}}\exp\left(-\mathrm{j}2\pi\frac{c}{\lambda KB}n_{R_0}\right)\cdot\exp\left(-\mathrm{j}\frac{4\pi}{\lambda}v_0m'T\right)\exp\left(-\mathrm{j}\frac{2\pi}{\lambda}a(m'T)^2\right)\cdot\mathrm{sinc}\left[\frac{1}{K}\left(n'-n_{R_0}\right)+m'\left(\frac{\tan\varphi}{K}-\frac{V_{\mathrm{e}}T}{\Delta r}\right)\right]$$



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3. Non-uniform fast Fourier transform

$$s_{\text{rot}}(n',m') = A_{\text{c}}\,\text{sinc}\left[\frac{1}{K}\left(n' - n_{R_0}\right)\right] \cdot \exp\left(-\text{j}\frac{2\pi c}{\lambda KB} n_{R0}\right)\exp\left(-\text{j}\frac{4\pi}{\lambda} v_0 m' T\right) \cdot \exp\left(-\text{j}\frac{2\pi}{\lambda} a(m'T)^2\right)$$

$$\hat{V}_{\text{e}} = \Delta r \frac{\tan\varphi}{KT}$$

$$\hat{v}_0 = 2\left[\hat{V}_{\text{e}} - \text{round}\left(\frac{\hat{V}_{\text{e}}}{v_{\text{b}}}\right)\cdot v_{\text{b}}\right]$$

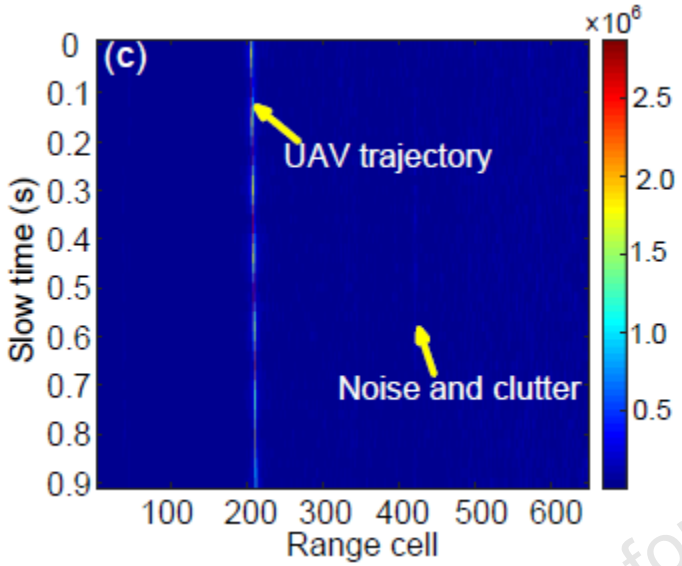
$$S_{\text{NuFFT}}\left(f_{(m'T)^2}\right) = \text{NuFFT}\left(s_{\text{azi}}(m')H_1(m')\right)$$

$$= \sum_{m'=-N_{\text{a}}/2}^{N_{\text{a}}/2-1} s_{\text{azi}}(m')H_1(m')\exp\left[-\text{j}2\pi f_{(m'T)^2}(m'T)^2\right]$$

$$= A_{\text{NuFFT}}\exp\left(-\text{j}\frac{2\pi c}{\lambda KB} n_{R_0}\right) p\left(f_{(m'T)^2} + \frac{a}{\lambda}\right)$$

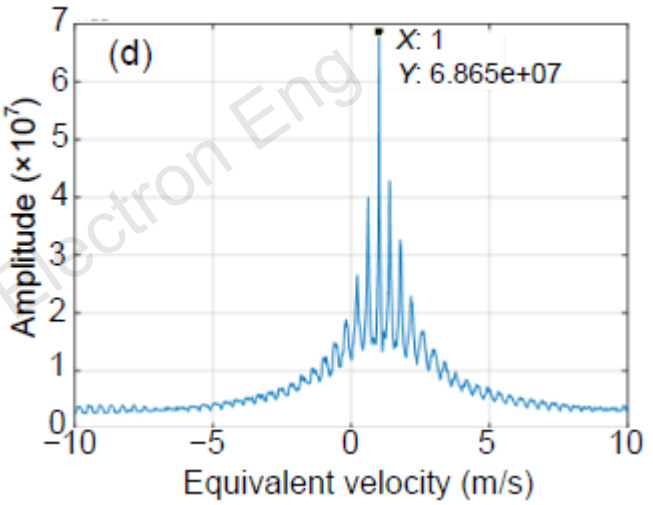
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Major results



UAV trajectory with range migration

In 0.92 s coherent time, the UAV moves across seven range cells and causes serious range migration.

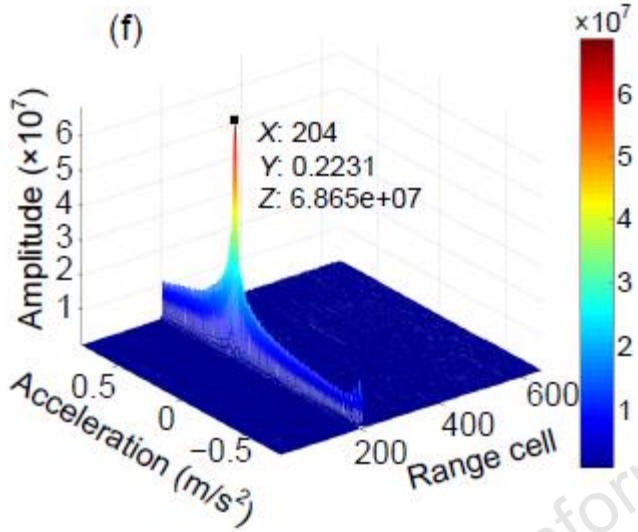


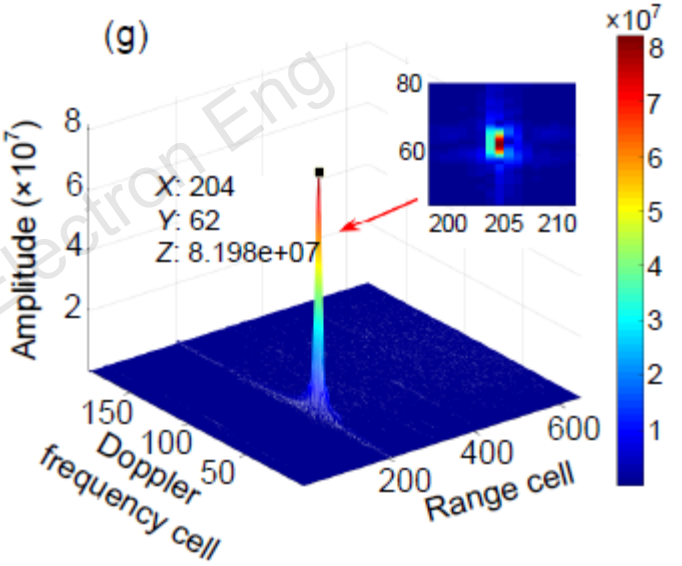
Equivalent velocity estimation result

The equivalent velocity can be estimated from the rotation angle, and the result is used to construct a phase compensation function.

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Major results (Cont'd)





Acceleration estimation result

After range migration correction, the non-uniform fast Fourier transform is used to estimate the target's acceleration.

Coherent integration result

Coherent integration is achieved after compensating for the range migration and Doppler frequency migration.

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Major results

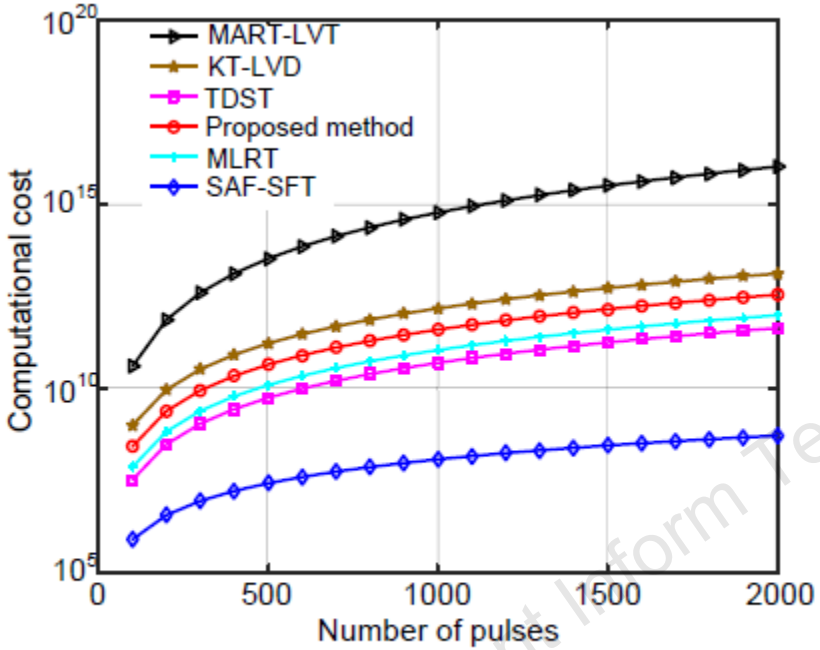


Fig. 2 Comparison results of computational complexity

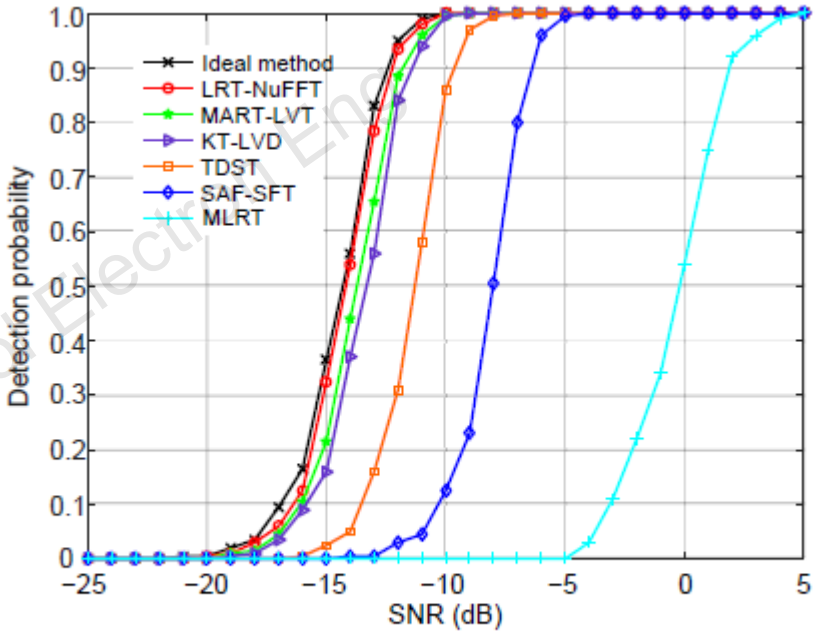


Fig. 5 Detection probability against the signal-to-noise ratio (SNR)

The proposed method has moderate computational complexity.

The proposed method has nearly the same detection ability as the ideal processing.

Conclusions

- A linear integration method is used to avoid the cross-term interference and performance loss.
- A novel phase compensation function is constructed with the help of the rotation angle.
- The non-uniform fast Fourier transform is used to achieve an efficient implementation of the proposed method.
- Nearly optimal detection performance can be obtained with much lower computational cost.

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