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

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

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# 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.

# 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.

# Method

1. Second-order keystone transform

$$S(f_{\mathrm{r}},t_m)=A_f\,\mathrm{rect}\left(\frac{f_{\mathrm{r}}}{B}\right)\exp\left(-\mathrm{j}4\pi f_{\mathrm{r}}\frac{N_{\mathrm{b}}v_{\mathrm{b}}t_m}{c}\right)\cdot\exp\left[-\mathrm{j}4\pi(f_{\mathrm{r}}+f_{\mathrm{c}})\frac{R_0+v_0t_m+0.5at_m^2}{c}\right]$$

$$t_m=\left(\frac{f_{\mathrm{c}}}{f_{\mathrm{r}}+f_{\mathrm{c}}}\right)^{1/2}t_{\mathrm{a}}$$

Second-order keystone transform

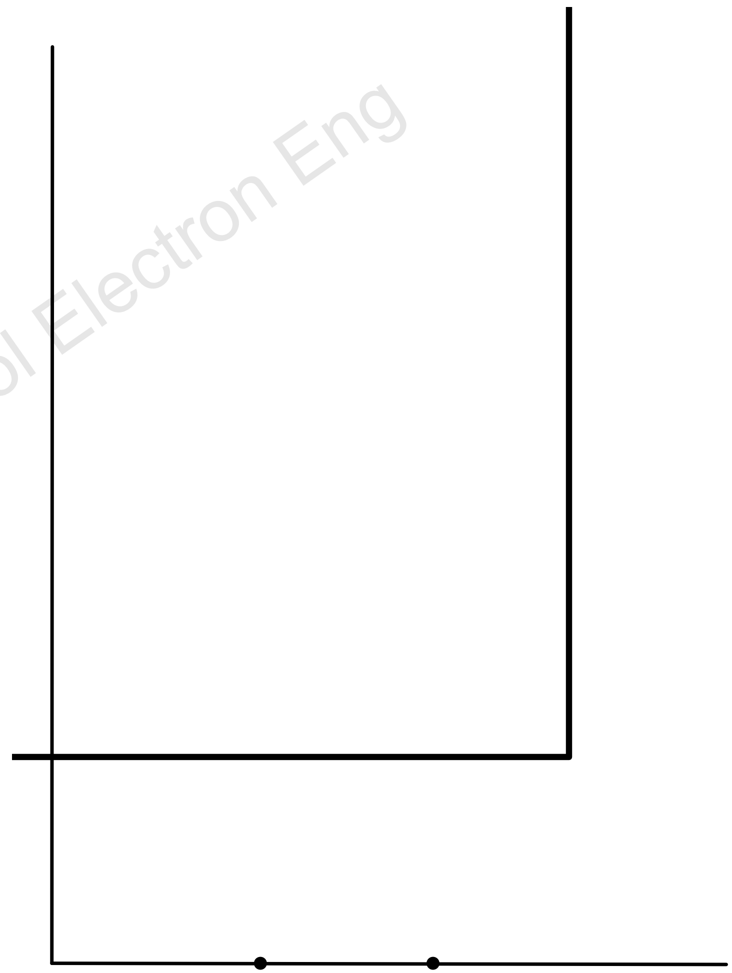
$$S_{\mathrm{SoKT}}(f_{\mathrm{r}},t_{\mathrm{a}})=A_f\,\mathrm{rect}\left(\frac{f_{\mathrm{r}}}{B}\right)\exp\left(-\mathrm{j}4\pi f_{\mathrm{r}}\frac{R_0+V_{\mathrm{e}}t_{\mathrm{a}}}{c}\right)\cdot\exp\left(-\mathrm{j}4\pi\frac{R_0+v_0t_{\mathrm{a}}+0.5at_{\mathrm{a}}^2}{\lambda}\right)$$

# 2. Location rotation transform

$$
\begin{aligned}
s_{\mathrm{SoKT}}(n,m) = {} & A_{\mathrm{c}}\,\mathrm{sinc}\left[\frac{1}{K}\left(n-n_{R_0}\right)-\frac{1}{\Delta r}V_{\mathrm{e}}mT\right] \\
& \cdot \exp\left(-\mathrm{j}2\pi\frac{c}{\lambda KB}n_{R_0}\right)\exp\left(-\mathrm{j}\frac{4\pi}{\lambda}v_0 mT\right) \\
& \cdot \exp\left[-\mathrm{j}\frac{2\pi}{\lambda}a(mT)^2\right]
\end{aligned}
$$

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

$$
\begin{aligned}
s_{\mathrm{rot}}(n',m') = {} & A_{\mathrm{c}}\exp\left(-\mathrm{j}2\pi\frac{c}{\lambda KB}n_{R_0}\right) \\
& \cdot \exp\left(-\mathrm{j}\frac{4\pi}{\lambda}v_0 m'T\right)\exp\left(-\mathrm{j}\frac{2\pi}{\lambda}a(m'T)^2\right) \\
& \cdot \mathrm{sinc}\left[\frac{1}{K}\left(n'-n_{R_0}\right)+m'\left(\frac{\tan\varphi}{K}-\frac{V_{\mathrm{e}}T}{\Delta r}\right)\right]
\end{aligned}
$$



# 3. Non-uniform fast Fourier transform

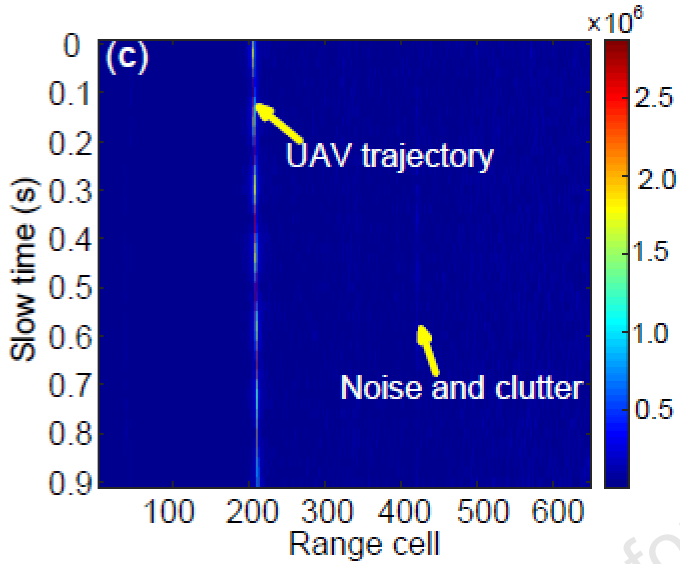
$$s_{\mathrm{rot}}(n',m') = A_{\mathrm{c}}\,\mathrm{sinc}\left[\frac{1}{K}\left(n'-n_{R_0}\right)\right] \cdot \exp\left(-\mathrm{j}\frac{2\pi c}{\lambda KB}n_{R0}\right)\exp\left(-\mathrm{j}\frac{4\pi}{\lambda}v_0 m'T\right) \cdot \exp\left(-\mathrm{j}\frac{2\pi}{\lambda}a(m'T)^2\right)$$

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

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

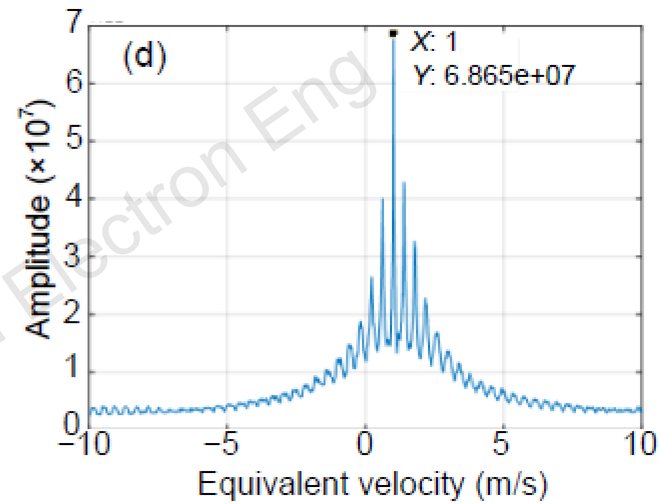
$$S_{\mathrm{NuFFT}}\left(f_{(m'T)^2}\right) = \mathrm{NuFFT}\left(s_{\mathrm{azi}}(m')H_1(m')\right) = \sum_{m'=-N_{\mathrm{a}}/2}^{N_{\mathrm{a}}/2-1} s_{\mathrm{azi}}(m')H_1(m')\exp\left[-\mathrm{j}2\pi f_{(m'T)^2}(m'T)^2\right] = A_{\mathrm{NuFFT}}\exp\left(-\mathrm{j}\frac{2\pi c}{\lambda KB}n_{R_0}\right)p\left(f_{(m'T)^2}+\frac{a}{\lambda}\right)$$

# Major results




**UAV trajectory with range migration**

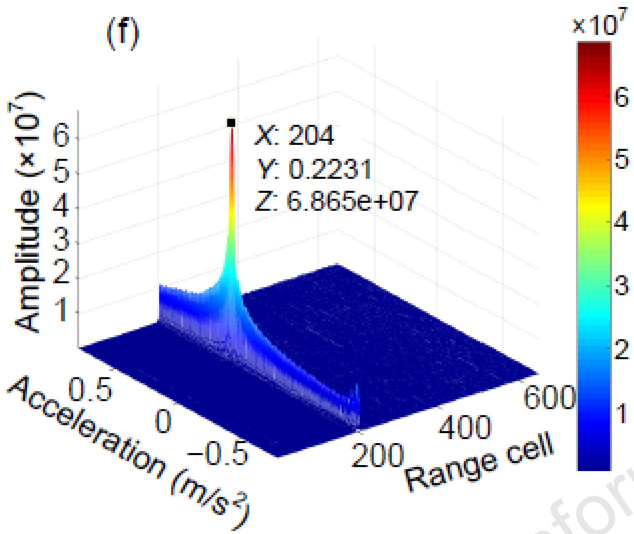
In 0.92 s coherent time, the UAV moves across seven range cells and causes serious range migration.

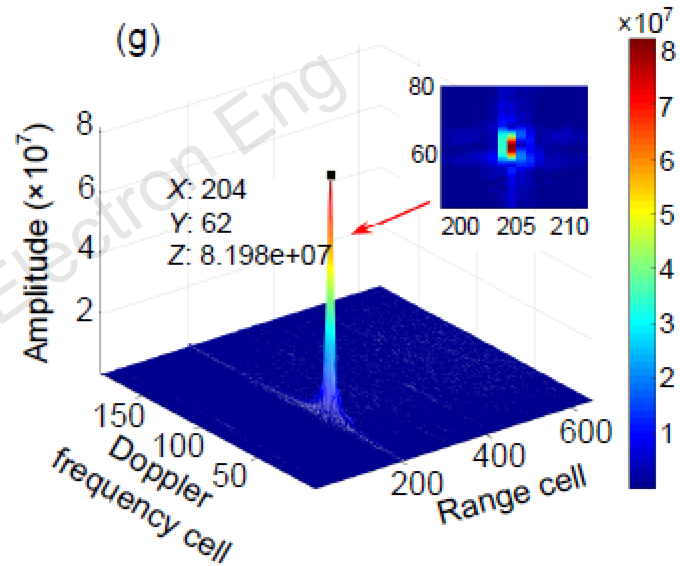



**Equivalent velocity estimation result**

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

# Major results (Cont'd)






**Acceleration estimation result**

**Coherent integration result**

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

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

# Major results

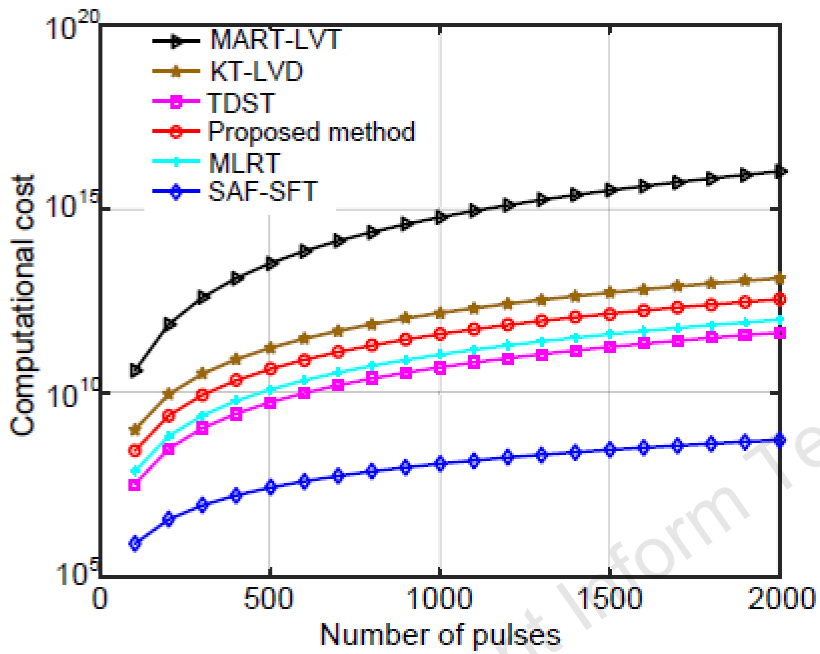



**Fig. 2 Comparison results of computational complexity**

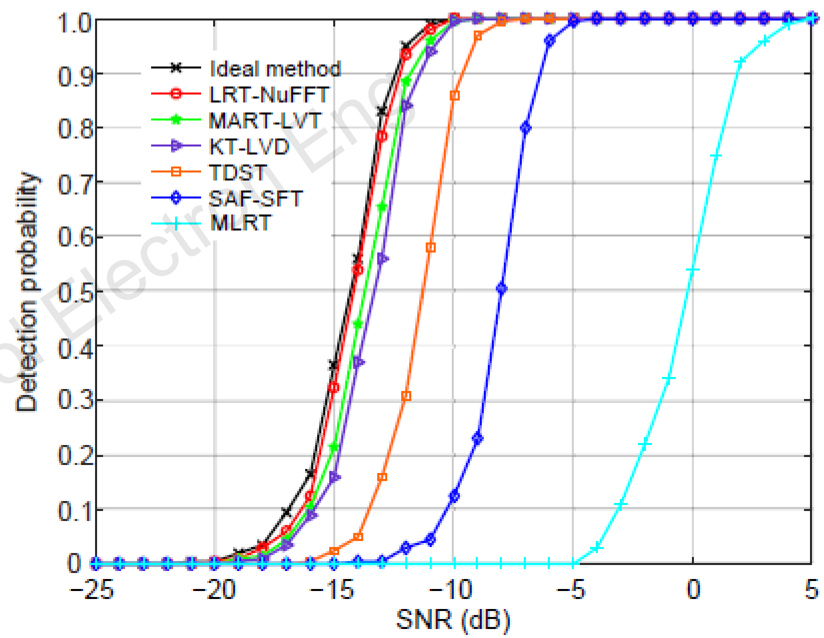



**Fig. 5 Detection probability against the signal-to-noise ratio (SNR)**

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.