Micro-Motion Parameter Extraction of Spinning Targets Based on Rotating Antenna

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Zhihao Wang, Fenglian Sun, Xiaochen Zhao,
Hang Yuan, Ying Luo, Qun Zhang

Abstract

The micro-Doppler effect is regarded as a unique feature of the target with micro-motion, which can provide important information for the classification and recognition of the target. In this paper, a three-dimensional (3D) micro-motion features extraction method of spinning target based on rotating antenna is proposed. In this new radar configuration, the micro-Doppler curve of spinning target is the addition of two sinusoidal signals, and the orthogonal matching pursuit (OMP) algorithm can be used to reconstruct the 3D micro-motion features of spinning target. The application cost of this method is low, and the requirements for radar system are not high. Simulation results verify the effectiveness of the proposed method.

Introduction

The micro-Doppler effect is considered to be a unique feature of the target with micro-motion, which can provide important information for target classification and recognition [1-2]. Existing monostatic radar can only achieve the radial micro-motion parameters extraction, but cannot obtain real micro-motion features [3]. In order to solve the problems existing in monostatic radars, 3D micro-motion features extraction method based on bistatic/ multistatic radar is proposed. In [4], the antenna is arranged in the shape of "L" to extract the 3D micro-motion features through the interference of echoes. However, this method requires high collaborative processing of echo data, and the application cost of multistatic radars is relatively high. Orbital angular momentum (OAM) carried by vortex electromagnetic waves can provide additional information for target detection due to its helical phase wavefront distribution, and has attracted more and more attention in the field of radar detection in microwave band [5]. In [5], the angular Doppler generated by the vortex electromagnetic wave can be used to achieve effective estimation of the true spinning radius, spinning frequency and tilt angle in arbitrary position. However, the vortex electromagnetic wave used in the field of radar detection is generated by uniform circle array (UCA), and the angular Doppler is determined by the modal of OAM, which is limited by the size of UCA. Therefore, it is necessary to design a new radar configuration to achieve low cost and easy collaborative 3D micro-motion features extraction.

In this paper, a new radar configuration based on rotating antenna is proposed [6]. In this configuration, only two narrowband antennas are required to achieve effective estimation of 3D micro-motion features of spinning targets, and the application cost is low and the collaborative processing of echo data is not complicated. An antenna moves uniformly in a circular motion, another antenna is fixed at the center of the circle, and the echos received by the two antennas are interfered. The phase of the interfered echo is the addition of the two cosine signals. Finally, the OMP algorithm can effectively reconstruct the true spinning radius, spinning frequency and tilt angle of the spinning target.

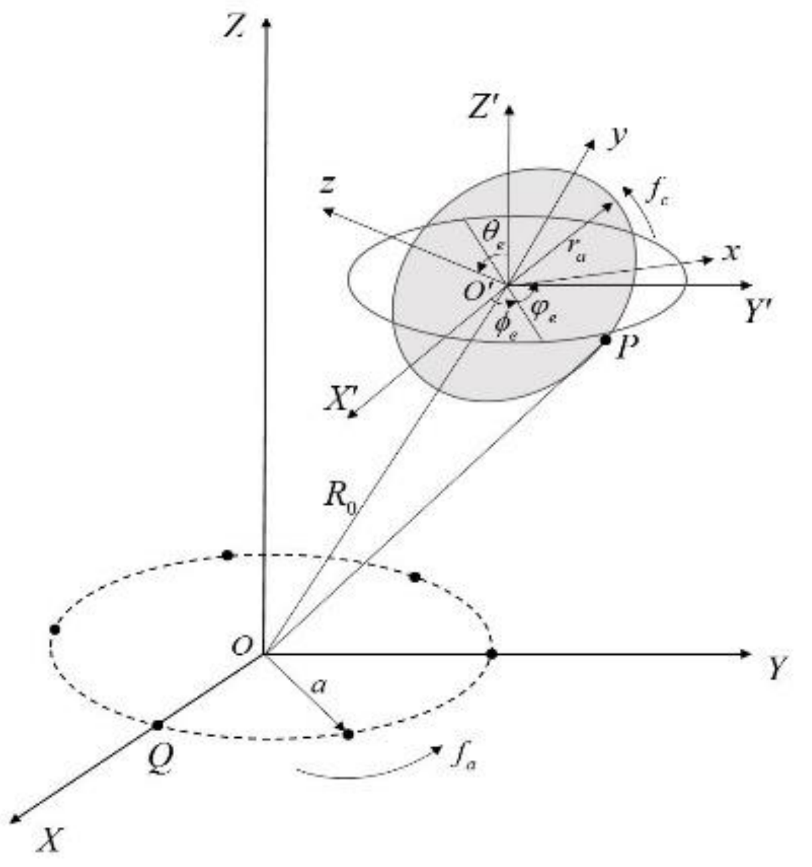


Fig. 1. Geometry of rotating antenna, fixed antenna and spinning target.

Micro-Doppler effect analysis and parameters extraction

Fig.1. shows the geometry of rotating antenna, fixed antenna and spinning target.

The desired micro-Doppler curve can be expressed as

$$f_{d1}(t_m)=\frac{4\pi}{\lambda}\begin{pmatrix} B_1(f_c - f_a)\sin\left(2\pi(f_c - f_a)t_m+\varphi_1\right)+ \\ B_2(f_c + f_a)\sin\left(2\pi(f_c + f_a)t_m+\varphi_2\right)\end{pmatrix}$$

In order to extract the micro-Doppler parameters in the echo signal, the atomic set can be constructed by setting different values of $(B_1,B_2,\varphi_1,\varphi_2)$, and the *l-th* atom in the atomic set can be expressed as

$$\boldsymbol{A_m}^{(l)}=\exp\left(\text{-j}\frac{4\pi}{\lambda}B_1^{(l)}\cos\left(2\pi\left(f_c-f_a\right)t_m+\varphi_1^{(l)}\right)\right)$$
$$\cdot\exp\left(\text{-j}\frac{4\pi}{\lambda}B_2^{(l)}\cos\left(2\pi\left(f_c+f_a\right)t_m+\varphi_2^{(l)}\right)\right)$$

The echo vector $s_c(t_m)$ is decomposed by OMP algorithm, and the atom with the best matching is searched successively according to the principle of maximum correlation. The residual component of the *l-th* decomposition satisfies $\boldsymbol{s}_l(t_m)=\boldsymbol{s}_{l\text{-}1}(t_m)-A_{l-1}\boldsymbol{A_m}^{(l)}$.

After obtaining the values of $(B_1,B_2,\varphi_1,\varphi_2)$ by OMP algorithm, the 3D micro-motion parameters of spinning target can be estimated.

$$\begin{cases}\hat{\theta}_e=\text{acos}\left(\dfrac{B_1+B_2}{B_1-B_2}\right)\\ \hat{\varphi}_e=\dfrac{\varphi_1+\varphi_2}{2}\\ \hat{\phi}_e=\dfrac{\varphi_1-\varphi_2}{2}\\ \hat{r}=\dfrac{2B_1R_0}{a\left(1+\cos\hat{\theta}_e\right)}\quad\text{or}\quad\hat{r}=\dfrac{2B_2R_0}{a\left(1-\cos\hat{\theta}_e\right)}\end{cases}$$

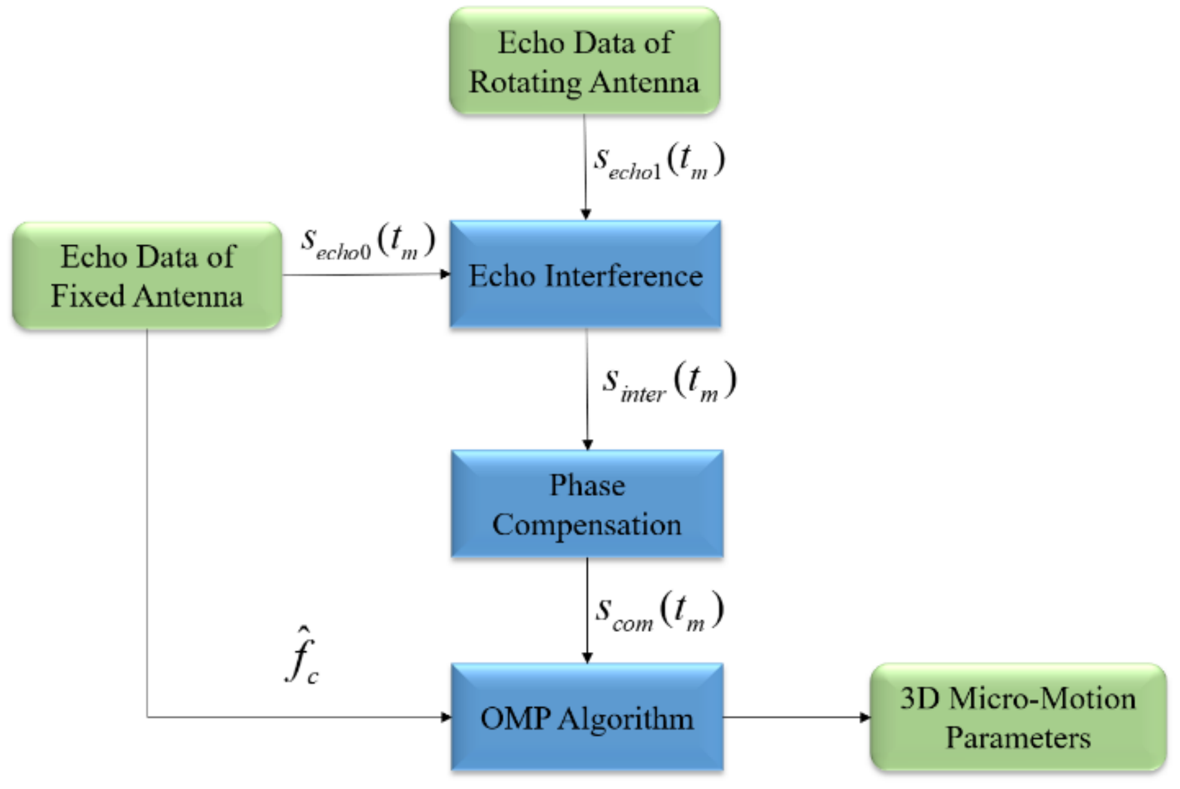


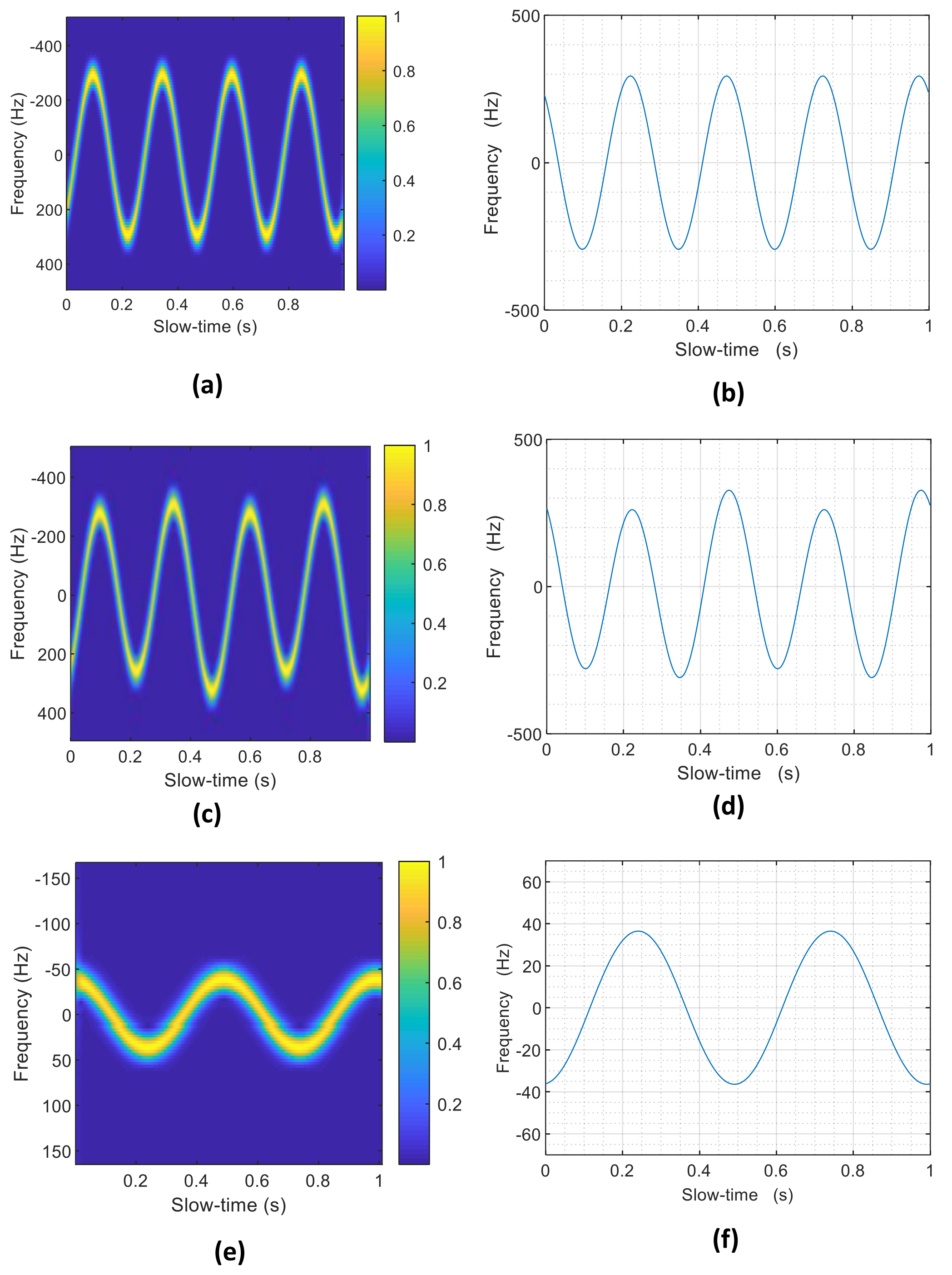
Fig. 2. Flow chart of the proposed method.

Results

The echo and theoretical micro-Doppler curve of the fixed antenna are shown in **Fig. 3(a)** and **(b)** respectively, which are the same as the sinusoidal micro-Doppler curve of the traditional monostatic radar. The echo and theoretical micro-Doppler curve of the rotating antenna are shown in **Fig. 3(c)** and **(d)** respectively, which are superimposed by four sinusoidal curves with different amplitude, frequency and initial phase. The sinusoidal component of the spinning frequency can be eliminated by multiplying the conjugate of the echo signal from the rotating antenna and the echo signal from the fixed antenna. The echo and the theoretical micro-Doppler curve at this time are shown in **Fig. 3(e)** and **(f)**. Then the signal is passed through the band-stop filter to eliminate the sinusoidal component with frequency *fa*. The micro-Doppler curve at this time is composed of two sinusoidal curves superimposed. By applying OMP algorithm to the final micro-Doppler curve, the curve parameters can be reconstructed to estimate the 3D micro-motion parameters of the spinning target. The estimation results are shown in **Table 1**.

Table 1. Estimated results of the proposed method.

Parameters	True value	Estimated value	Normalized error
f_c	4 Hz	4 Hz	0%
r	0.5 m	0.4928 m	1.4414%
θ_e	π/4 rad	0.7638 rad	2.7517%
Φ_e	π/3 rad	1.0996 rad	5%
φ_e	π/5 rad	0.6283 rad	0.003%



(a) (b) (c) (d) (e) (f)

Fig. 3. The micro-Doppler effect based on rotating antenna.

Discussion

It can be seen that the estimation errors of spinning frequency, true spinning radius and tilt angle of the spinning plane obtained by the proposed method are all below 3%, and the estimation errors of the other two initial Euler angles are also below 5%. It can be said that the proposed method achieves high-precision 3D micro-motion features extraction of the spinning target.

Conclusions

In this paper, a new radar configuration based on rotating antenna is proposed. The echo signal whose phase is modulated by two cosine signals is obtained through interfering with the echoes received by the rotating antenna and fixed antenna. Then, OMP algorithm is used to effectively extract the 3D micro-motion features of the spinning target. The normalized error of the true spinning radius, spinning frequency and tilt angle of the spinning target are all less than 3%.

This paper is a preliminary attempt to realize 3D micro-motion features extraction by using rotating antenna. Next, the 3D micro-motion features extraction method of spinning target with multiple scattering points will be researched, and the feasibility of the proposed method in practical scenes should be verified.

References

1. V. C. Chen, F. Li, S. . -S. Ho and H. Wechsler, "Micro-Doppler effect in radar: phenomenon, model, and simulation study," IEEE Transactions on Aerospace and Electronic Systems, vol. 42, no. 1, pp. 2-21, Jan. 2006.
2. X. Chen, N. Su, Y. Huang and J. Guan, "False-Alarm-Controllable Radar Detection for Marine Target Based on Multi Features Fusion via CNNs," IEEE Sensors Journal, vol. 21, no. 7, pp. 9099-9111, 1 April1, 2021.
3. X. Bai and Z. Bao, "High-Resolution 3D Imaging of Precession Cone-Shaped Targets," IEEE Transactions on Antennas and Propagation, vol. 62, no. 8, pp. 4209-4219, Aug. 2014.
4. Y. Luo, Y. Chen, Y. Sun and Q. Zhang, "Narrowband Radar Imaging and Scaling for Space Targets," IEEE Geoscience and Remote Sensing Letters, vol. 14, no. 6, pp. 946-950, June 2017.
5. Y. Wang, K. Liu, H. Liu, J. Wang and Y. Cheng, "Detection of Rotational Object in Arbitrary Position Using Vortex Electromagnetic Waves," IEEE Sensors Journal, vol. 21, no. 4, pp. 4989-4994, 15 Feb.15, 2021.
6. Z. Wang, Y. Luo, K. Li, H. Yuan, and Q. Zhang, "Micro-Doppler Parameters Extraction of Precession Cone-Shaped Targets Based on Rotating Antenna," Remote Sensing, vol. 14, no. 11, p. 2549, May 2022.
7. Y. Luo, Q. Zhang, C. Qiu, S. Li, T. Soon Yeo, "Micro-Doppler feature extraction for wideband imaging radar based on complex image orthogonal matching pursuit decomposition," IET Radar, Sonar Navig., vol. 7, no. 8, pp. 914–924, Oct. 2013.

Email: afeuwzh@163.com