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Discriminate the Decoy and Target Using Frequency Profile Modeling in the Radar Terminal Guidance

SONG Zhi-yong, XIAO Huai-tie, ZHU Yi-long and LU Zai-qi
ATR Key Laboratory, National University of Defense Technology, Changsha, China
E-mail: zhiyongsong@163.com

Abstract. In the radar terminal guidance, discriminate the decoy and target is the primary problem to counter the towed radar active decoy jamming and achieve the precision strike. In the course of angle deception of the decoy, the triangular geometry relationship among the missile, the target and the decoy alters, and the Doppler frequency of the target and the decoy is different. In this paper, based on the detailed analysis of the frequency separability, the frequency profile modeling of the target and decoy is obtained and the separation of them is achieved based on the existed Doppler difference, through adopting the L class of Wigner Ville Distribution method. Then in aid of the high frequency resolution monopulse angle measurement, the angle information of the target and decoy is gained, and the discrimination is achieved. The simulation results validated the availability.

Keywords: Towed radar active decoy (TRAD); Doppler difference; Frequency separation; Frequency profile modeling

1. Introduction

The improvement of the ECM and the stealth technology makes a serious challenge to the precision guided weapons. The weapon systems are required to have the ability to counter against all kinds of interference, identify true and false targets, and deal with multi-targets. Towed active radar decoy (TRAD) is a novel means of deception and jamming, mainly used to destruct the seeking and tracking of the radar seeker, reduce the probability of exposure of the target, and improve the viability of the target. Because of its high-performance, high-controllability and low cost advantages, it becomes the most effective way to deceive and threaten the air-to-air missiles [1]. The main approach to counter the TRAD jamming is to extract the difference of characteristics between the echoes of target and decoy, and distinguish them in some feature dimension. The Doppler difference between the target and decoy is generated from the different radial velocity of target and decoy relative to missile, which due to their triangular geometry relationship and different antenna beam pointing direction. The existence of Doppler difference offers the chance to separate the target and the decoy in frequency. The echo, which the radar seeker receives form the target and the decoy within the radar beam can be seen as a multi-component linear FM signal[2]. So the time-frequency analysis method[3-5]can be use to get the frequency profile modeling of the target and decoy. Based on the separation in Doppler, the high frequency resolution monopulse angle measurement technology can be used to measure the angle of the target and decoy, and then achieve the discrimination. This paper analyzes the Doppler separability between the target and decoy under the head-on attack scene, adapts LWVD[6] to get the separation of target and decoy in Doppler and realize the discrimination of the target and the decoy successfully.

2. Separability Analysis

In the terminal guidance phase, the head-on attack scene is one of the major attack scenarios which the target often encounters. Under the head-on attack, the geometric relationship among the missile, target and decoy is different, and that the difference of Doppler comes from the target and decoy is not the same. With the distance that between the missile and target diminishing and the geometric relationships changing, the Doppler difference also alters. Fig.1 is the 2-Dimension geometric relationship under the head-on attack.

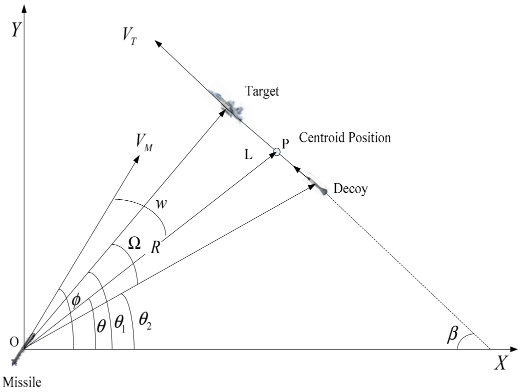


Fig.1 The geometric relationship under the head-on attack

In Figure 1 the target tows the radar decoy in horizontal flight and both fly with the same speed V_T . P is the centroid position from the radar seeker pointing. The missile flies with the speed V_M . Ω is the angle interval between the target and decoy . β is the angle between V_T and the horizon and ϕ is the angle between V_M and the horizon. $w=\phi-\theta$, and $\Omega=\theta_1-\theta_2$ .The interference suppression ratio, which defined as the power ratio of the decoy and the target, is assumed equal to K, so the aiming bearing of the radar seeker is

$$\theta=\frac{\Omega}{2}\frac{K^2-1}{K^2+1} \tag{1}$$

The centroid position P between the target and the decoy can be calculated according to θ . Assume V_T , V_M and ϕ are invariable during a processing interval, and the Doppler difference between the target and the decoy under the head-on attack can be expressed as

$$\begin{aligned}\Delta f_d=&\frac{2V_T\left[\cos\left(\beta+\theta_1\right)-\cos\left(\beta+\theta_2\right)\right]}{\lambda}\\&+\frac{2V_M\left[\cos\left(\phi-\theta_1\right)-\cos\left(\phi-\theta_2\right)\right]}{\lambda}\end{aligned} \tag{2}$$

Set P_{FPM} as the separability factor which is defined as following equation.

$$P_{FPM}=\frac{\left|\Delta f_d\right|}{\delta_f} \tag{3}$$

Where, δ_f is the Doppler resolution of the radar system. Equation (3) shows that lager P_{FPM} indicates stronger separability. Therefore, the large Δf_d and the small δ_f mean the strong separability.

In the terminal guidance, the angle interval Ω is small, so $\sin\Omega\approx\Omega$ and $(\theta_1+\theta_2)/2\approx\theta$ .Decompose (2), the following equations can be obtained.

$$\Delta f_d\approx\left[-\frac{2V_T}{\lambda}\sin\left(\beta+\theta\right)+\frac{2V_M}{\lambda}\sin\left(w\right)\right]\Omega \tag{4}$$

The distance between the missile and the decoy is equal to L, so Ω can be approximated as:

$$\Omega\approx\frac{L\sin(\theta)}{R} \tag{5}$$

Thus, (5) can be simplified as

$$\Delta f_d\approx\left[-\frac{2V_T}{\lambda}\sin\left(\beta+\theta\right)+\frac{2V_M}{\lambda}\sin\left(w\right)\right]\frac{L\sin\left(\theta\right)}{R} \tag{6}$$

The factors P_{FPM} under the head-on attack scenario is

$$P_{FPM}=\left|-V_T\sin\left(\beta+\theta\right)+V_M\sin\left(w\right)\right|\frac{2L\sin\left(\theta\right)}{\lambda R\delta_f} \tag{7}$$

In fact, the above analysis about the Doppler differences between the target and decoy only from the triangular geometric relationship is not enough and cannot describe the true situation of difference under the whole attack course, which because the motion of the missile is constrained by the guide law and overload and the fights of the target and the decoy is also constrained by the acceleration of maneuver. Therefore, the terminal guided attack scenario must be introduced to the Doppler analysis, and the correct status of Doppler differences of the target and decoy can be attained.

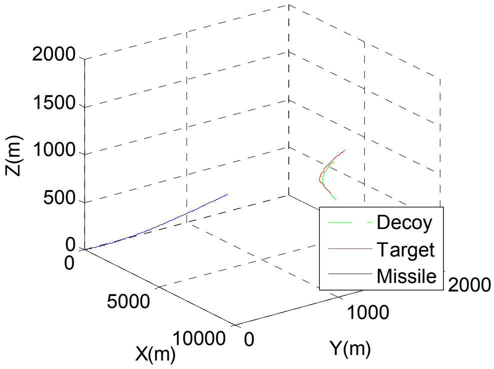


Fig.2. The motion trajectory under head-on attack

Figure 2 shows the 3-Dimension motion trajectories under the head-on attack scenario. The acceleration of maneuver of the target and decoy is 6g. Missile adopts the Proportional Navigation guidance with the proportional coefficient is 3. The interference suppression ratio is K=10[3], and the baseline of radar beam points to the decoy, the radar beam-width $BW = 6^{\circ}$.When the angle interval Ω is greater than $1/2BW$, the target will escape the radar beam and the trajectory stop.

Figure 3 shows the curve of the Doppler differences when the initial attack angle of the missile is between $\pm 20^{\circ}$. The length of the dragged line is L=150m.

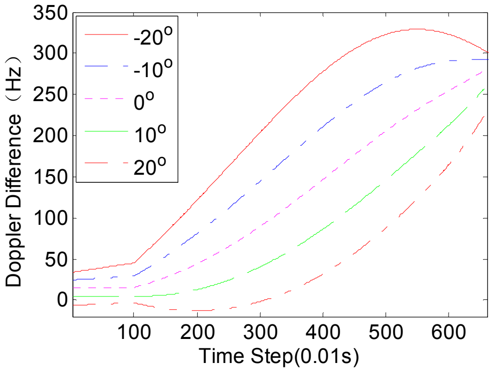


Fig.3.Doppler differences under the head-on attack scenario

In Figure 3, in the initial phase, the target and the decoy have nearly the same Doppler frequency, which because the triangular geometrical relationships were not formed. With the advance in time, the distance between the target and decoy diminishes, the geometrical relationship is formed gradually, and the Doppler differences gradually become large too. The Doppler difference is existed and variable under the head-on attack scenario. If the Doppler resolution of the radar seeker is smaller than the difference, the separation of the target and the decoy in the frequency domain will be able to achieve.

3. Frequency Profile Modeling

Above analysis results show that the Doppler difference between the target and the decoy is not constant during certain accumulation time and it is not a smooth movement. If still using the traditional FFT method, may cause the Doppler spectrum of the target and the decoy broaden and overlap each other, and they cannot separate correctly. At present, in the ISAR imaging, the time-frequency analysis methods are usually used to deal with such non-stationary signals. Among these methods, the instantaneous imaging method that based on the second time-frequency analysis is most widely used, and the imaging effect of the method is good and the computation load is less. So, here, the L-class of Wigner Ville Distribution (LWVD) is applied to the antijamming scene to obtain the frequency profile modeling of the target and decoy, and realize the separation of them in the Doppler domain utilizing the advantages of enhancing the cross resolution and suppressing the cross-term. LWVD and its Point Spread Function (PSF) are brief discussed as follows.

LWVD was firstly proposed by Stankovic, with the analytic signal $s(t)$, LWVD is defined as

$$\mathrm{LWVD}(t,\omega)=\int s^{L}\left(t+\frac{\xi}{2L}\right)s^{*L}\left(t-\frac{\xi}{2L}\right)\exp(-\mathrm{j}\omega\xi)\,\mathrm{d}\xi \tag{8}$$

Where, L is a positive integer, and when L = 1, LWVD degenerates to WVD. LWVD has the same or similar good properties as WVD, such as satisfying the edge conditions, time shift invariant and frequency shift invariance [6].

In order to measure the cross resolution quantificational, its point spread function is derived in following. The target and the decoy can be seen as two strong scattering points, and for any ideal scattering point target P(x, y), the echo signal can be written as

$$s(f,t)=\exp\left(-\mathrm{j}\frac{4\pi f}{c}r_t\right)\mathrm{rect}\left(\frac{f-f_0}{B}\right)\mathrm{rect}\left(\frac{t}{T}\right) \tag{9}$$

The echo is first compressed to get the sequences of range profiles. That is to implement IFT to the frequency f and get as follows.

$$\begin{aligned}s'(\tau,t)&=B\,\mathrm{sinc}\left[B\left(\tau-\frac{2}{c}x\right)\right]\exp\left[\mathrm{j}2\pi f_0\left(\tau-\frac{2}{c}x\right)\right]\\&*\exp\left[-\mathrm{j}2\pi\left(\alpha t+\beta t^2\right)\right]\mathrm{rect}\left(\frac{t}{T}\right)\end{aligned} \tag{10}$$

Where

$$\alpha=\frac{2f_0}{c}y\omega;\beta=-\frac{f_0}{c}x\omega^2 \tag{11}$$

After obtaining the compressed signal $s'(\tau,t)$, then implement LWVD and take the outcome at time $t=0$ as the result of the cross differentiation. Set $\xi'=\xi/2L$, and obtain as

$$\begin{aligned}s''(\tau,\nu)&=2LB^{2L}\,\mathrm{sinc}^{2L}\left[B\left(\tau-\frac{2}{c}x\right)\right]\\&*\int\exp(\mathrm{j}4\pi L\alpha\xi')\exp(-\mathrm{j}4\pi L\nu\xi')\,\mathrm{rect}\left(\frac{\xi'}{T}\right)\mathrm{d}\xi'\\&=2LB^{2L}T\,\mathrm{sinc}^{2L}\left[B\left(\tau-\frac{2}{c}x\right)\right]\mathrm{sinc}\left(\frac{\nu-\alpha}{T/2L}\right)\end{aligned} \tag{12}$$

Get the Modulus of the results of (12) and calibrate it, so the PSF is described as

$$I(r,l)=2LTB^{2L}\left|\mathrm{sinc}^{2L}\left(\frac{r-x}{\Delta r}\right)\right|\left|\mathrm{sinc}\left(\frac{l-y}{\Delta l/2L}\right)\right| \tag{13}$$

Scale the time delay τ and frequency shift ν as

$$\tau=\frac{r}{B\Delta r};\nu=\frac{l}{T\Delta l} \tag{14}$$

Where, Δr is the range resolution and Δl is the azimuth resolution.

$$\Delta r=\frac{c}{2B};\Delta l=\frac{c}{2f_0\omega T} \tag{15}$$

The PSF Shows that, LWVD transform is not sensitive to the second phase term in the echo, the response function of the scattering point of orientation is sinc(•), and the azimuth resolution increases L times than that at the WVD (L = 1).

Similar to WVD, the LWVD method also has the problem of cross-term. The paper [7] adapts the method of windowing in frequency domain to suppress the cross terms and get a good result. Of course, that also may lead to some loss of the resolution too. That paper also showed the expression of the recursive calculation for LWVD based on STFT.

$$\begin{aligned}\mathrm{LWVD}_1(n,k) &= \left|\mathrm{STFT}(n,k)\right|^2 \\ &\quad + 2\sum_{i=1}^{N_\mathrm{w}} \mathrm{Re}\left\{\mathrm{STFT}(n,k+i)\cdot \mathrm{STFT}(n,k-i)\right\}\end{aligned} \tag{16}$$

$$\begin{aligned}\mathrm{LWVD}_{2L}(n,k) &= \mathrm{LWVD}_L^2(n,k) \\ &\quad + 2\sum_{i=1}^{N_\mathrm{w}} \mathrm{LWVD}_L(n,k+i)\cdot \mathrm{LWVD}_L(n,k-i)\end{aligned} \tag{17}$$

Where, $2N_W+1$ is the length of the window.

After the LWVD, the frequency profile modeling of the target and decoy is obtained, and the separation of the target and the decoy in Doppler is achieved.

4. Discrimination and Tracking

When the target and the decoy separate in Doppler domain after the LWVD method, they lie at different Doppler resolution cell of the radar seeker. Therefore, the normal monopulse angle measurement technology can be used to obtain the respective angle information of the target and the decoy. The separated Doppler and their respective angle information can be used to discriminate the target and decoy correctly and realize the track of the target in the terminal guidance.

In the terminal guidance, the target and the decoy are both living within the radar beam of the radar seeker, the monopulse sum/diff data of the radar receiver can be expressed as

$$\begin{aligned}S_\Sigma(t) &= \sum_{i=1}^{2} S_{\Sigma i}(t) = \sum_{i=1}^{N} 4r_iG_0F(\Delta\theta_i)\cos\left(\frac{\pi d}{\lambda}\Delta\theta_{ai}\right)\cos\left(\frac{\pi d}{\lambda}\Delta\theta_{ei}\right) \\ &\qquad \bullet\exp\left[\mathrm{j}2\pi(f_I+f_{di})t+\varphi_{\Sigma i}\right] \\ S_{\Delta a}(t) &= \sum_{i=1}^{2} S_{\Delta ai}(t) = \sum_{i=1}^{N} 4r_iG_0F(\Delta\theta_i)\sin\left(\frac{\pi d}{\lambda}\Delta\theta_{ai}\right)\cos\left(\frac{\pi d}{\lambda}\Delta\theta_{ei}\right) \\ &\qquad \bullet\exp\left[\mathrm{j}2\pi(f_I+f_{di})t+\varphi_{\Delta ai}\right] \\ S_{\Delta e}(t) &= \sum_{i=1}^{2} S_{\Delta ei}(t) = \sum_{i=1}^{N} 4r_iG_0F(\Delta\theta_i)\cos\left(\frac{\pi d}{\lambda}\Delta\theta_{ai}\right)\sin\left(\frac{\pi d}{\lambda}\Delta\theta_{ei}\right) \\ &\qquad \bullet\exp\left[\mathrm{j}2\pi(f_I+f_{di})t+\varphi_{\Delta ei}\right]\end{aligned} \tag{18}$$

After passing through the zero Intermediate Frequency (IF) processing of the radar receiver and executing the LWVD processing, the amplitude and phase information of the sum/diff data are

$$\begin{aligned}\Sigma(f_{di}) &= \Sigma R(f_{di}) + j\Sigma I(f_{di}) \\ \Delta A(f_{di}) &= \Delta AR(f_{di}) + j\Delta AI(f_{di}) \\ \Delta E(f_{di}) &= \Delta ER(f_{di}) + j\Delta EI(f_{di}) \\ \varphi_{\Sigma i} &= \arctan^{-1}\left[\Sigma I(f_{di})/\Sigma R(f_{di})\right] \qquad \mathrm{i=1,2} \\ \varphi_{\Delta ai} &= \arctan^{-1}\left[\Delta AI(f_{di})/\Delta AR(f_{di})\right] \\ \varphi_{\Delta ei} &= \arctan^{-1}\left[\Delta EI(f_{di})/\Delta ER(f_{di})\right]\end{aligned} \tag{19}$$

According to the normal phase comparison monopulse principle, the angle information of the target can be measured as

$$\begin{aligned}\Delta\varphi &= \frac{2\pi}{\lambda} d\sin\theta \\ \left|\tan\frac{\Delta\varphi}{2}\right| &= \left|\frac{\Delta(f_d)}{\Sigma(f_d)}\right|\end{aligned} \tag{20}$$

So, after utilizing the high frequency resolution monopulse angle measurement technology, the azimuth and elevation information of the target and decoy can be obtained.

$$\begin{aligned}\Delta\theta_a\left(f_{di}\right) &= \frac{\lambda}{\pi d}\arctan^{-1}\left(\frac{\left|\Delta A\left(f_{di}\right)\right|}{\left|\Sigma\left(f_{di}\right)\right|}\right)\\ \Delta\theta_e\left(f_{di}\right) &= \frac{\lambda}{\pi d}\arctan^{-1}\left(\frac{\left|\Delta E\left(f_{di}\right)\right|}{\left|\Sigma\left(f_{di}\right)\right|}\right)\end{aligned} \tag{21}$$

Through (18)-(21), the angle parameter of the target and the decoy are both gained, and then combine the information of the attack scenario, the discrimination of them can be achieved. In the TRAD jamming, the power of the decoy is large than that of the target, and according to (1), the baseline of the radar beam will point close to the decoy, so the angle of the decoy measured by (21) is near 0, and that of the target is away form 0. So, this relationship will help to discriminate the target and the decoy correctly.

5. Simulation

In this part, the simulation experiments are used to validate the effect of the proposed algorithm. The 3-Dimension trajectory of the simulation is shown in Figure 3, where the carrier frequency is 6GHz, the pulse repetition frequency is 100 KHz, and the initial angle of attack is set to 6^o.

Figure 4 shows the result of the separation of the target and decoy in Doppler based on the LWVD method under the head-on attack. The coherent integration time is 20ms, and the corresponding Doppler resolution is 50Hz. In the head-on attack, the radial velocity of the missile and the target, and the time of the terminal guidance are short. Considering the constraint of guide law and overload, there should remain enough time to adjust the ballistic and bearing of the radar seeker after discriminating the target and decoy. So in the simulation, the time from 0s to 4.5s is considered.

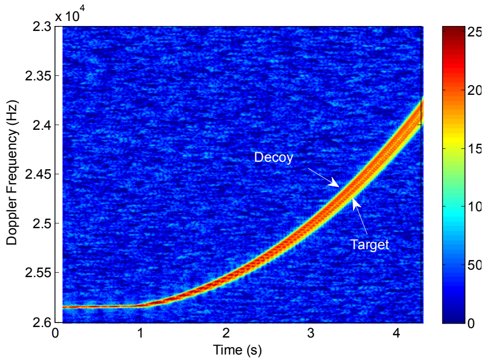
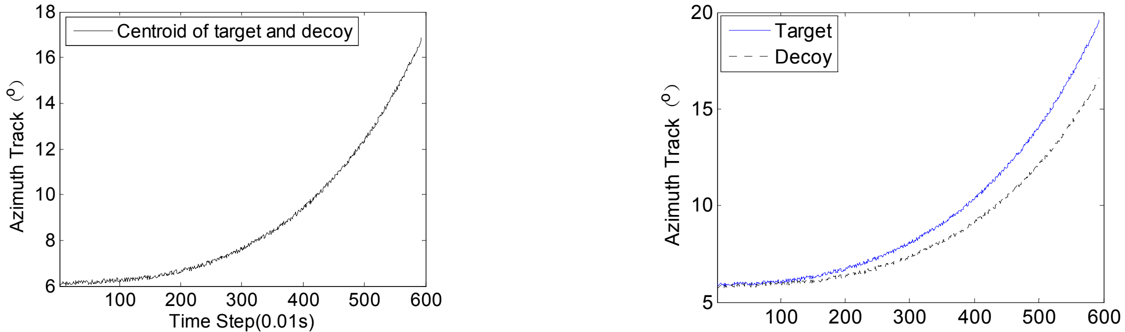


Fig.4. Doppler separation under the head-on attack scenario

Figure 4 shows that in the head-on attack scene and during the terminal guidance, the frequency spectrum of the target and the decoy starts to broaden obviously from the 2s after the LWVD, and separate gradually at 3ths, then at 3.5ths, the frequency spectrum separation is obvious. This result is consistent to Figure 3.

Figure 5 shows the azimuth tracking curves of the target and the decoy on the two conditions. One is the condition that Doppler separation is not adopted, and another is realizing the separation and obtains the respective angle information of the target and decoy.



(a) Azimuth track when not separate in Doppler

(b) The azimuth track when separate in Doppler

Fig.5. The azimuth track of the target and decoy

Figure 5 (a) is the azimuth track curve of the target and decoy which do not separate in Doppler because not adopt the LWVD. In the figure, the missile will track the centroid of the target and decoy because they do not separate and the angle of the centroid will be obtained by the monopulse angle measurement. While in Figure 5 (b), in aid of the LWVD, the separation of the target and decoy is achieved in Doppler, and the respective angle information of the target and decoy can be obtained, so the missile will initiate the track of them. With the information of the angle relationship, the target can be easily picked out and the radar seeker will track the target steadily.

6. Conclusion

The Doppler difference of the target and the decoy is existed in the head-on attack scenario. This paper adopts the LWVD to get the frequency profile modeling and separate the target and decoy in the Doppler. Then the angle information of the target and decoy are gained by the high frequency resolution monopulse angle measurement, and the discrimination of the target and decoy is achieved. The simulation proves that the method proposed in this paper is available and effective.

7. References

[1] Wang Wan-tong, Pang Guo-rong. Towed Radar Active Decoy [J], Electronic Warfare Technology, 1998,13(3): 21-26.

[2] Shi Yin-shui, Ji Hong-bing, Wang Lei. Formation radar targets automatic detection method based on Choi-Williams Trispectrum [J]. Modern Radar, 2007, 29(7):34-37.

[3] Chen V C, Qian S. Joint time-frequency transform for radar range-Doppler imaging [J]. IEEE Transactions on Aerospace and Electronic Systems, 1998, 34(2): 486−499.

[4] Chen V C, Miceli W J. Time-varying spectral analysis for radar imaging of maneuvering targets [J]. IEE Proceedings—Radar, Sonar and Navigation, 1998, 145(5): 262–268.

[5] Berizzi F, Mese E Dallse, Diani M, Martorella M. High-resolution ISAR imaging of maneuvering targets by means of the range instantaneous Doppler technique: Modeling and performance analysis [J]. IEEE Transactions on Imaging Processing, 2001, 10(12): 1880−1890.

[6] Stankovic L. A multitime definition of Wigner higher order distribution: L-Wigner distribution [J]. IEEE Signal Processing Letters, 1994, 1(7): 106−109.

[7] Stankovic L. A method for improved distribution concentration in the time-frequency analysis of multicomponent signals using the L-Wigner distribution [J]. IEEE Transactions on Signal Processing, 1995, 43(5): 1262−1268.