A New Application of Zernike Moment to AN/TPY-2 Radar

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***Abstract*—The AN/TPY-2 radar becomes a threat to our ballistic missile because it can recognize the shape of targets, such as true warhead and false warhead. The theory of Zernike moment is analyzed in the paper and the jamming effect evaluation model based on Zernike moment is build. According to the change of Zernike moment by different jamming model to AN/TPY-2, the evaluation method is found. The evaluation experiment is carried out and the results of simulation prove the method is corrective and effective.**

***Index Terms*—AN/TPY-2, jamming effect, Zernike Moment, evaluation**

I. Introduction

The AN/TPY-2 radar are the eyes of THAAD system, it is the most advanced missile defense radar, which can watch and follow the launch of ballistic missile. Its radar range can exceed 1000 miles. the AN/TPY-2 radar becomes a threat to our ballistic missile because it can recognize the shape of targets clearly, such as true warhead and false warhead. It becomes more and more important in modern electronic warfare.

It is a difficulty problem to counter the AN/TPY-2 radar because of its new work principle and tactical use. good effect evaluation method can verify the effective jamming method to AN/TPY-2. The recognition of true and false missile is a very important use of AN/TPY-2 radar. The recognition probability more depends on the choice of target characters, which are the base of target recognition.

From the point of target recognition, the new evaluation method based on Zernike Moments is researched in the paper. By comparing the change of target recognition characters, the evaluation process is carried out through calculating the difference of two picture's Zernike Moments [1], [2].

II. The Analysis of AN/TPY-2 Radar Performance

AN/TPY-2 radar is the key radar of THAAD, its performance is very big. It was developed by Raytheon Corporation of the United States. Its development goes through three stages: demonstration and validation model stage, user operational assessment system model stage, engineering manufacturing model stage. There are differences in the antenna area and the number of elements between the three phases of radar. The AN/TPY-2 radar can be deployed independently to be early missile warning radar, it can also be deployed with launcher car, interception missile fire control and communication unit of THAAD together.

AN/TPY-2 radar is made up of antenna, power system, cooling system and active power system. The area of radar antenna is 9.2 square meters. The number of transmitting and receiving elements is 25334. Peak power of array elements is16W. Radar Average Power is 60-80KW. Because the wavelength of AN/TPY-2 radar is short and the size is very big, its beams are very narrow and resolution is very high. It can track and recognize the true and false missile warhead. The longest range of AN/TPY-2 radar detection can be reached 2300km, it detection range can reach 1700km,when the reflective cross section of target is one square meter.

Common AN/TPY-2 radar signal waveform patterns are shown in Table I.

TABLE I. AN/TPY-2 Radar Waveform Patterns

Working mode	bandwith	waveform patterns
search	Narrow band	LFM
imaging	broadband	LFM

High two-dimensional resolution and ultra-long detection distance make AN/TPY-2 radar t largest and most powerful missile early warning radar in the world. Its shape is shown in the Fig. 1 below [3], [4].

(a) A view of the shape of AN/TPY-2 radar

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(b)another view of the shape of AN/TPY-2 radar

Figure 1. The shapes of AN/TPY-2 radar.

THAAD is the only ground-based system in the world today capable of intercepting ballistic missiles both inside and outside the atmosphere. THAAD is not only a shield, it can also ingest intelligence and monitor opponents. If the THAAD system is stationed on the Korean peninsula, it will not only affect North Korea, but also the strategic and tactical missiles deployed in the Far East of China and Russia. Theoretically speaking, Chinese "Dongfeng-21D" and "Dongfeng-26" series of anti-ship ballistic missiles maneuvering in the eastern coastal areas are in danger of "early exposure".

III. The Basic Rpinciple of the Evaluation Method

The AN/TPY-2 radar is usually used to search, track, recognize the flying targets of incoming missile,. The target characters are the base of target classification, and the target recognition probability lie on the choice of target characters mostly. The following characters are often used to recognize target: geometry moment, invariants of geometry moment, figure characters, airscrew modulated characters. Because of having the ability of circumgyration fixity, the moment character is one of the most important characters for target recognition[5].

A. Character of Moment

One two-dimension grey-degree picture $f(x,y), x = 0,......, M-1, y = 0,...., N-1$ is given, and then the geometry origin moment with $p+q$ rank can be determined as following formula [6]:

$$m_{pq} = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} x^p y^q f(x,y), p,q = 0,1,2..... \quad (1)$$

In order to make these instantaneous variables fixed when the target is moving, the center moment can be determined as follows:

$$u_{pq} = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} (x-\bar{x})^p (y-\bar{y})^q f(x,y), p,q = 0,1,2..... \quad (2)$$

In order to make center moment unrelated to zoom, it can be changed as following:

$$\eta_{pq} = \frac{u_{pq}}{u_{00}^{\gamma}} \quad (3)$$

$$\gamma = \frac{p+q}{2} + 1 \quad (4)$$

B. Character of Zernike Moment

One two-dimension grey-degree picture $f(x,y), x = 0,......, M-1, y = 0,...., N-1$ is given, and then the two-dimension Zernike moment can be determined as following formula [6]:

$$Z_{mn} = \frac{m+1}{\pi} \iint_{x^2+y^2\le 1} f(x,y)[V_{mn}(x,y)]^* dxdy, m \ge 0 \quad (5)$$

where, m and n is integer, and $m-|n|$ is even numbers, $n \le m$, in the Polar coordinate space, the Zernike moment can be determined as follows:

$$Z_{mn} = \frac{m+1}{\pi} \int_0^1 \int_0^{2\pi} f(r,\theta) V_{mn}(r,\theta) r dr d\theta, r \le 1 \quad (6)$$

$$r = \sqrt{x^2+y^2}\ ,\ \theta = \tan^{-1}(y/x) \quad (7)$$

In the formula, r is the length of vector about origin, θ is the included angle between vector r and X axis, the Element structure of Complex polynomial $V_{mn}(x,y)$ can be showed as:

$$V_{mn}(x,y) = V_{mn}(r,\theta) = R_{mn}(r)\exp(jn\theta) \quad (8)$$

$$R_{mn}(r) = \sum_{k=0}^{(m-|n|)/2} (-1)^k \frac{(m-k)!}{k!(\frac{m+|n|}{2}-k)!(\frac{m-|n|}{2}-k)!} r^{m-2k} \quad (9)$$

If $f(x,y)$ is data imaging, Z_{mn} can be calculated by the following formula:

$$Z_{mn} = \frac{m+1}{\pi} \sum_x \sum_y f(x,y) V_{mn}^*(r,\theta), x^2+y^2 \le 1 \quad (10)$$

The picture is destroyed by the jamming, at the same time , the Zernike moment of target image are changed. Because Zernike moment features are used for target recognition, So the probability of target recognition will be greatly reduced. Based on the above considerations, new evaluation method of jamming effect are proposed in the paper. the Zernike moment difference ΔZ between two images before and after interference can be got through two images. Under the same JSR, The bigger difference, the better the interference.

IV. Verification of Interference Test

For experimental convenience, we use the ideal missile point target model. In this paper, noise jamming models are used to interfere the AN/TPY-2 radar. Model of strategic missiles is simulated as Fig. 2.

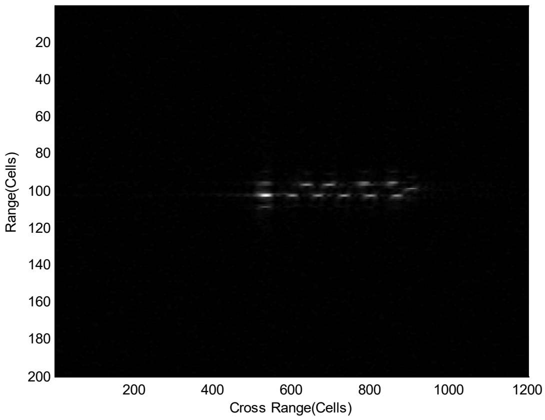


Figure 2. The original image of missile.

There are many forms of noise jamming. Noise AM jamming and noise FM jamming are selected in the paper [7]. The mathematical expression of Noise AM is as follows.

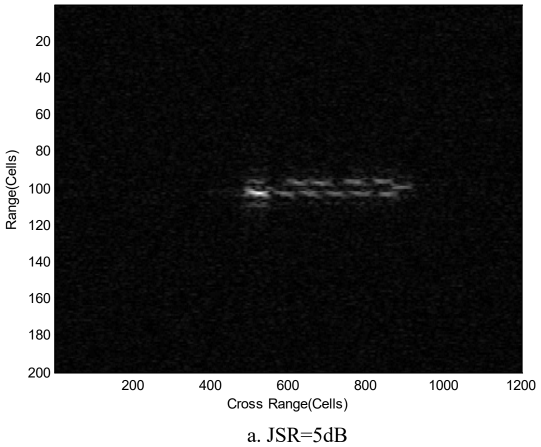
$$J(t)=(U_0+u_n(t))\cos(2\pi f_0 t+\varphi) \quad (11)$$

In the formula, $u_n(t)$ represents modulation noise. It is a wide-sense stationary stochastic process, its mean is zero and variance is σ_n^2, U_0 represents amplitude of carrier wave, f_0 is carrier frequency, φ is the original phase of carrier wave.

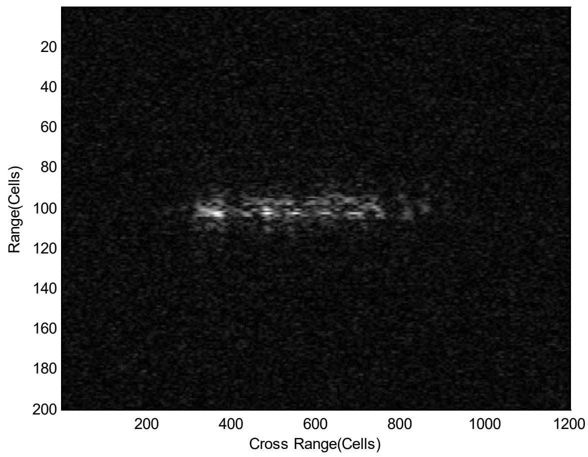
The mathematical expressions of noise FM is as follows [8]:

$$J(t)=U_0\cos[2\pi f_j t+2\pi k_{FM}\int_0^t u(\tau)d\tau+\phi] \quad (12)$$

In the formula, $u(t)$ represents modulated noise. It is a wide-sense stationary stochastic processes, its mean is zero and variance is σ_n^2, U_0 represents the amplitude of carrier wave, f_i is the carrier frequency, φ is the original phase of carrier wave, k_{FM} is the coefficient of frequency modulation. Under different JSR, the image of the missile is shown in the figure below.

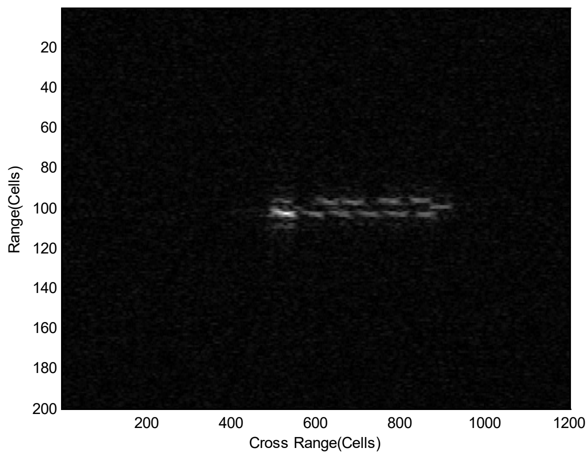


a. JSR=5dB

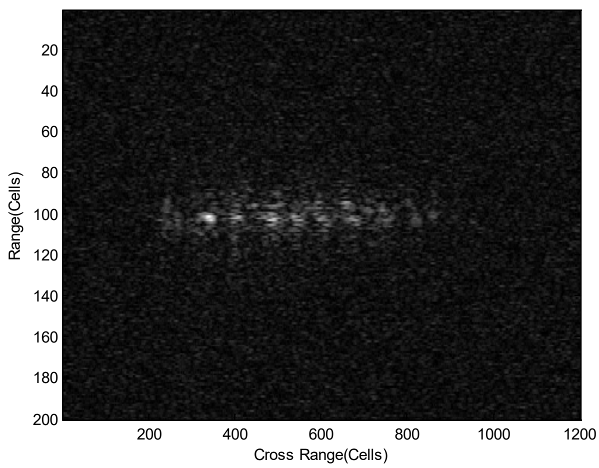


b. JSR=10dB

Figure 3. Missile image under noise AM jamming.



a. JSR=5dB



b. JSR=10dB

Figure 4. Missile image under noise FM jamming.

Fig. 3 and Fig. 4 are images of targets disturbed by different interference patterns with the same JSR (5dB and 10dB), When JSR equals 5dB, The outline of the target in Fig. 2 is very clear, but the outline of the target in Fig. 3 is a little vague. When JSR equals 10 dB, The outline of the target in Fig. 3 is a bit vague, but it can still be distinguished, however the target image in Fig. 4 has been completely destroyed and cannot be distinguished. Through the change of the target image, we can conclude that the interference effect of noise FM is better than the interference effect of noise AM.

V. Jamming Effect Evaluations Method Based on the Difference of Zernike Moment

According to the mathematical model of noise jamming above, the jamming experiment are conducted. For different jamming patterns, Under different JSR, the Zernike Moments characteristics of the image are calculated separately. The relationship between JSR and the Zernike Moments characteristics difference is shown in the Fig. 5.

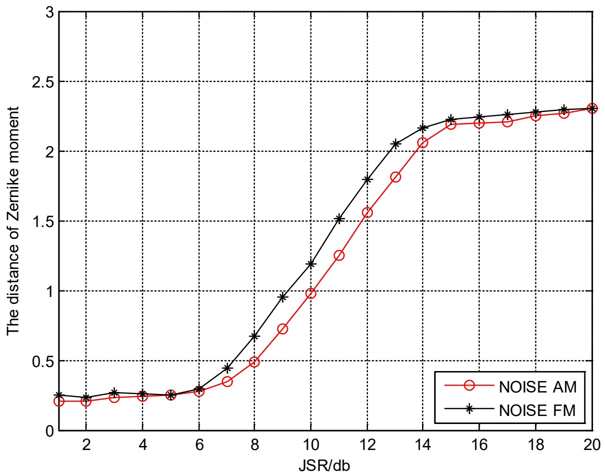


Figure 5. The relationship between JSR and the Zernike moments difference

Through Fig. 5, we can draw some conclusions:

Noise jamming is effective for the AN/TPY-2 radar, as the jamming signal energy increases, the image becomes more and more blurred. The AN/TPY-2 radar won't be able to correctly identify the warheads. And that's what the jamming is all about.

The Zernike Moment characteristic is an important feature of the image and an important feature of target recognition. As the jamming signal energy increases, the Zernike Moment difference between the two images before and after the jamming will become larger and larger.

However, when the jamming signal energy is the same, the Zernike Moment characteristics of different jamming signals are different. Using this, we can evaluate the effects of different jamming models. The jamming effect of the corresponding jamming pattern with large feature difference is good.

Of course, this method has disadvantage too. With the increasing of jamming signal energy, the two curves coincide. We cannot evaluate the jamming effect according to curves at this time.

VI. Conclusions

The AN/TPY-2 radar is the eye of THAAD system, the military function of it become more and more important, it has become a big threat to our ballistic missile, so it has a very big significance to research the jamming and jamming effect evaluation technology on it. The Zernike Moments are analyzed deeply and applied to evaluate the jamming effect on AN/TPY-2. Through the change of the distance of characters, the method of quantitative jamming effect evaluation is carried out. It has such merit as computed easily, also has been proved corrective and effective by the results of simulation.

It is not accurate to evaluate the jamming effect using one index, we will find more than two indexes to evaluate jamming effect comprehensively in the future work .

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Cui rui conducted the research; zhujing analyzed the data; Wang Tianyun and He Bin Helped collect a lot of literature.; all authors had approved the final version.

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