

New target detection method in strong active jamming background for polarimetric radar

Yuliang Chang^{1a)}, Ling Wen², and Huanyao Dai³

¹ School of Electronic Science and Engineering, NUDT,
Changsha, Hunan, 410073, China

² School of Computer Science, NUDT,
Changsha 410073, China

³ State Unit 63892 of PLA, Luoyang 471003, China
a) leon0203@sohu.com

Abstract: A new method of target detection for polarimetric radar in the presence of strong active jamming is proposed. Based on analysis of the polarization characterizations of the signals received by polarimetric radar, the target detection is achieved through testing on the polarization information. Comparing with the traditional method of target detection made in time-frequency domain, the detection performance of the new method is improved because the influence of the strong active jamming is avoided. The performance of the new method is analyzed by simulation experiment.

Keywords: polarization, detection, active jamming, polarimetric radar

Classification: Microwave and millimeter wave devices, circuits, and systems

References

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1 Introduction

Polarization, together with the amplitude, time, frequency, phase, and bearing descriptors of radar signals, completes the information which can be obtained on target returns [1, 2, 3]. Therefore, the polarimetric radar, which takes advantage of polarization diversity, has accessed the improvement in target detection ability, anti-jamming ability, and target classification and identification [4, 5]. As a subject of recurring interest, the optimal detection algorithm of target embedded in noise has been studied with consideration of the polarization characterizations of target echoes. Although the performance of target detection is improved in these studies, the effect of strong active jamming is untouched in these studies.

Based on analysis of the polarization characterizations of the received signals, a novel detection method for polarimetric radar is proposed. Through this method, the target returns embedded in strong active jamming can be detected by exploiting the polarization information. The performance of this method is testified by simulation experiment.

2 Target detection based on polarization information

2.1 Analysis of the polarization characterization

In strong active jamming background, the received signals contaminated by the jamming can be described as

$$\mathbf{e}_r(t) = \begin{bmatrix} e_{sh}(t) + e_{jh}(t) + n_{rh}(t) \\ e_{sv}(t) + e_{jv}(t) + n_{rv}(t) \end{bmatrix} \quad (1)$$

here, $[e_{jh}, e_{jv}]^T$ is the active jamming, $n_{rh}(t)$, $n_{rv}(t)$ represent the additional white Gaussian noise (AWGN), $e_{sh}(t)$, $e_{sv}(t)$ is the target returns.

If the polarization of the active jamming is stable during the receiving period of the polarimetric radar, and the polarization can be expressed by Jones Vector as $[1, \rho_j]^T$, the received signal shown in (1) can be rewritten as

$$\mathbf{e}_r(t) = \begin{bmatrix} e_{sh}(t) + e_{jh}(t) + n_{rh}(t) \\ e_{sv}(t) + \rho_j e_{jh}(t) + n_{rv}(t) \end{bmatrix} \quad (2)$$

Therefore, the outputs of the matched filters will be

$$\begin{cases} \hat{o}_{hh}(t) = o_{hh}(t) + \dot{o}_{hh}(t) + o_{hh}^n(t) \\ \hat{o}_{hv}(t) = o_{hv}(t) + \dot{o}_{hv}(t) + o_{hv}^n(t) \\ \hat{o}_{vh}(t) = o_{vh}(t) + \dot{o}_{vh}(t) + o_{vh}^n(t) \\ \hat{o}_{vv}(t) = o_{vv}(t) + \dot{o}_{vv}(t) + o_{vv}^n(t) \end{cases} \quad (3)$$

here, o_{mn} is the convolution result of the target echo e_{sm} and the signal h_n , o_{mn}^n is the convolution result of the noise n_{rm} and h_n , where h_n represents the matched filter signal corresponding to the emitting signal e_{tn} , $\dot{o}_{mn}(t) = e_{jm}(t) * h_n(t)$; and $m, n = h, v$.

Ordinarily, there is a time area $[t_a, t_b]$ in the receiving period of the polarimetric radar where the target returns do not exist. If the noise can be ignored, there is

$$\frac{\hat{o}_{vh}}{\hat{o}_{hh}} = \frac{\hat{o}_{vv}}{\hat{o}_{hv}} = \rho_j, \quad t_a \leq t \leq t_b \quad (4)$$

For the time area $[t_c, t_d]$ where the target returns are present

$$\begin{cases} \frac{\hat{o}_{vh}(t)}{\hat{o}_{hh}(t)} = \frac{o_{vh}(t) + \dot{o}_{vh}(t)}{o_{hh}(t) + \dot{o}_{hh}(t)} \\ \frac{\hat{o}_{vv}(t)}{\hat{o}_{hv}(t)} = \frac{o_{vv}(t) + \dot{o}_{vv}(t)}{o_{hv}(t) + \dot{o}_{hv}(t)} \end{cases}, \quad t_c \leq t \leq t_d \quad (5)$$

Therefore, the condition of the equality $\frac{\hat{o}_{vh}}{\hat{o}_{hh}} = \frac{\hat{o}_{vv}}{\hat{o}_{hv}}$ becomes the Jam-Signal Ratio (JSR) $\gg 1$ or

$$o_{hh}o_{vv} - o_{vh}o_{hv} = (o_{vh} - \rho_j o_{hh})\dot{o}_{hv} - (o_{vv} - \rho_j o_{hv})\dot{o}_{hh} \quad (6)$$

Apparently, this equality is hard to be satisfied because of the presence of the target returns when JSR is not very large.

Unfortunately, the noise can not be ignored in most cases, therefore (4) can be recalculated as

$$\begin{cases} \frac{\hat{o}_{vh}(t)}{\hat{o}_{hh}(t)} = \rho_j \frac{1 + \frac{n_{rv}(t)*h_h(t)}{e_{jv}(t)*h_h(t)}}{1 + \frac{n_{rh}(t)*h_h(t)}{e_{jh}(t)*h_h(t)}} \\ \frac{\hat{o}_{vv}(t)}{\hat{o}_{hv}(t)} = \rho_j \frac{1 + \frac{n_{rv}(t)*h_v(t)}{e_{jv}(t)*h_v(t)}}{1 + \frac{n_{rh}(t)*h_v(t)}{e_{jh}(t)*h_v(t)}} \end{cases}, \quad t_a \leq t \leq t_b \quad (7)$$

It is obvious that $\frac{\hat{o}_{vh}(t)}{\hat{o}_{hh}(t)} \approx \frac{\hat{o}_{vv}(t)}{\hat{o}_{hv}(t)}$ when Jam-Noise Ratio (JNR) is large. Therefore, the conclusion can be made that

$$\begin{cases} H_1 : \frac{\hat{o}_{vh}(t)}{\hat{o}_{hh}(t)} \neq \frac{\hat{o}_{vv}(t)}{\hat{o}_{hv}(t)} \\ H_0 : \frac{\hat{o}_{vh}(t)}{\hat{o}_{hh}(t)} \approx \frac{\hat{o}_{vv}(t)}{\hat{o}_{hv}(t)} \end{cases} \quad (8)$$

here, H_1 represents the condition that the target is present, and H_0 represents the condition that the target is not present.

The precondition of is that is unsustainable because of the target returns and JSR should not be very large.

2.2 Detection method of target

Let $\rho_h = \frac{\hat{o}_{vh}}{\hat{o}_{hh}}$, $\rho_v = \frac{\hat{o}_{vv}}{\hat{o}_{hv}}$, eq.(8) can be represented as

$$\begin{cases} |\rho_h - \rho_v| \neq 0 & H_1 \\ |\rho_h - \rho_v| \approx 0 & H_0 \end{cases} \quad (9)$$

Based on (8) and Neyman-Pearson criterion, target detection can be described as two hypothetical test problem

$$|\rho_h - \rho_v| \underset{H_0}{\overset{H_1}{\geq}} \eta \quad (10)$$

And the detection threshold η should be determined based on the false alarm probability P_f .

In condition H_0 ,

$$\kappa = (\rho_h - \rho_v | H_0) = \frac{\dot{o}_{vh} + o_{vh}^n}{\dot{o}_{hh} + o_{hh}^n} - \frac{\dot{o}_{vv} + o_{vv}^n}{\dot{o}_{hv} + o_{hv}^n} = \frac{\rho_j + \frac{o_{vh}^n}{\dot{o}_{hh}}}{1 + \frac{o_{hh}^n}{\dot{o}_{hh}}} - \frac{\rho_j + \frac{o_{vv}^n}{\dot{o}_{hv}}}{1 + \frac{o_{hv}^n}{\dot{o}_{hv}}} \quad (11)$$

Let $k_{mh} = \frac{o_{mh}^n}{\dot{o}_{hh}}$, $k_{mv} = \frac{o_{mv}^n}{\dot{o}_{hv}}$, $m = h, v$, (11) can be simplified as

$$\begin{aligned} \kappa &= \frac{\rho_j + k_{vh}}{1 + k_{hh}} - \frac{\rho_j + k_{vv}}{1 + k_{hv}} \\ &= \frac{\rho_j(k_{hv} - k_{hh}) + k_{hv}k_{vh} - k_{hh}k_{vv} + k_{vh} - k_{vv}}{k_{hh}k_{hv} + k_{hh} + k_{hv} + 1} \\ &\approx \rho_j(k_{hv} - k_{hh}) + (k_{vh} - k_{vv}) \end{aligned} \quad (12)$$

where, the precondition $JNR \gg 1$ is used.

Since the noise n_h, n_v are zero-mean AWGN, k_{mn} , $m, n = h, v$ obey zero-mean Gaussian distribution according to Gaussian distribution property [1]. Therefore, κ also obeys the zero-mean Gaussian distribution. Suppose the variance of κ is σ_κ , $|\kappa|$ follows Rayleigh distribution. The probability density function (PDF) can be described as

$$f(|\kappa|) = \frac{|\kappa|}{\pi\sigma_\kappa} \exp\left(-\frac{|\kappa|^2}{\sigma_\kappa}\right) \quad (13)$$

And the false alarm probability is

$$P_f(\eta) = \int_\eta^\infty f(x)dx \quad (14)$$

here, $f(*)$ is the PDF given in (13).

Finally, the detection threshold can be obtained by $\eta = Q^{-1}(P_f)$, where $Q^{-1}(*)$ is the reverse function of the right tail probability function given in (14).

Therefore, the method of target detection based on the polarization characterization can be summarized as following:

Step1: the received signals of H, V polarized channels are fed into the matched filters. The outputs of the matched filters are $\hat{o}_{hh}(t)$, $\hat{o}_{hv}(t)$, $\hat{o}_{vh}(t)$ and $\hat{o}_{vv}(t)$;

Step2: the polarization ratio of the matched filter h_m is obtained by $\rho_m = \hat{o}'_{vm}/\hat{o}'_{hm}$, $m = h, v$;

Step3: the target is detected by comparing the ratios difference $|\rho_h - \rho_v|$ with the detection threshold η .

3 Detection performance experiment

In condition H_1 , the difference between ρ_h and ρ_v is

$$\kappa' = (\rho_h - \rho_v | H_1) = \frac{o_{vh} + \dot{o}_{vh} + o_{vh}^n}{o_{hh} + \dot{o}_{hh} + o_{hh}^n} - \frac{o_{vv} + \dot{o}_{vv} + o_{vv}^n}{o_{hv} + \dot{o}_{hv} + o_{hv}^n} \quad (15)$$

Let $\rho'_h = \frac{o_{vh} + \hat{o}_{vh}}{o_{hh} + \hat{o}_{hh}}$, $\rho'_v = \frac{o_{vv} + \hat{o}_{vv}}{o_{hv} + \hat{o}_{hv}}$, $k'_{mh} = \frac{o_{mh}^n}{o_{hh} + \hat{o}_{hh}}$, $k'_{mv} = \frac{o_{mv}^n}{o_{hv} + \hat{o}_{hv}}$, $m = h, v$, (15) can be simplified as

$$\kappa' = \frac{\rho'_h + k'_{vh}}{1 + k'_{hh}} - \frac{\rho'_v + k'_{vv}}{1 + k'_{hv}} \approx \rho'_h - \rho'_v + \rho'_h k'_{hv} - \rho'_v k'_{hh} + k'_{vh} - k'_{vv} \quad (16)$$

Based on (15), it can be concluded that κ' obey Gaussian distribution $\mathcal{N}(\mu', \sigma')$, where $\mu' = \rho'_h - \rho'_v$ and $\sigma' = \rho_h'^2 \sigma_{hv} + \rho_v'^2 \sigma_{hh} + \sigma_{vh} + \sigma_{vv}$. And σ_{mn} , which is the variance of k'_{mn} , $m, n = h, v$, is directly proportional with the noise power according to the Gaussian distribution property [4].

Apparently, $|\kappa|$ obeys folded normal distribution with the PDF as

$$f(|\kappa|, \mu', \sigma') = \frac{1}{\sqrt{2\pi\sigma'}} \exp\left\{-\frac{(-|\kappa| - \mu')}{2\sigma'}\right\} + \frac{1}{\sqrt{2\pi\sigma'}} \exp\left\{-\frac{(|\kappa| - \mu')}{2\sigma'}\right\} \quad (17)$$

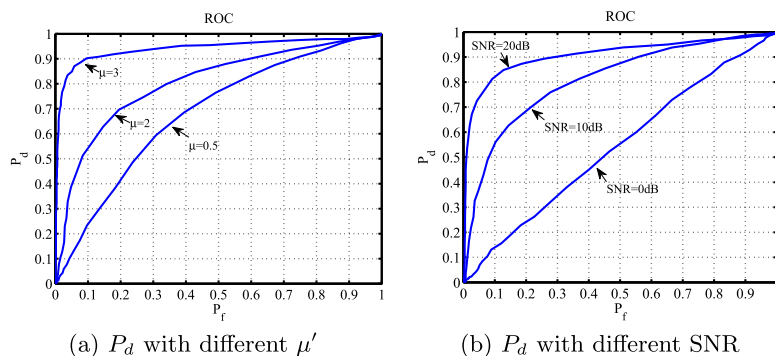
Therefore the detection probability of target is

$$P_d = \int_{\eta}^{\infty} f(x, \mu', \sigma') dx \quad (18)$$

here, $f(*, \mu', \sigma')$ is the PDF given in (17).

It is obvious the probability of target detection is associated with η , μ' and σ' . Since the detection threshold is decided previously, the detection performance is determined by μ' and σ' . Based on the property of PDF $f(|\kappa|, \mu', \sigma')$, the target detection probability will be increased when μ' is larger or σ' is smaller. It means that detection performance will be improved when the difference between ρ_h and ρ_v is larger, and the power of the noise is smaller, which will be proved by simulation. The major parameters of the simulation are listed as follows: the emitting signals are dual-frequency pulses with carrier frequency 10.48 GHz, the frequency difference between the emitting signals of the two channels is 20 MHz, pulse width is 0.3 μ s, PRI is 20 μ s. The active jamming is amplitude-modulation noise with the carrier frequency 10.49 GHz, the polarization ratio of the active jamming is $\sqrt{\frac{1}{2}} + \sqrt{\frac{1}{2}}j$. The detection performance under different conditions are shown in Fig. 1

In Fig. 1 (a), the ROC curves are given when JSR is 30 dB, SNR is 20 dB, and μ' is 0.5, 2.0 and 3.0 respectively. The ROC curves are shown in Fig. 1 (b)



(a) P_d with different μ' (b) P_d with different SNR

Fig. 1. The ROC curves with different μ' and SNR

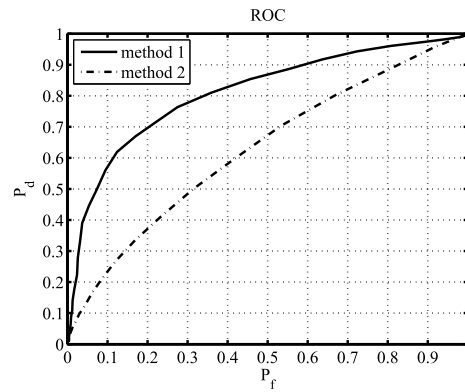


Fig. 2. The detection performance analysis results

when $\text{JSR} = 30 \text{ dB}$, $\mu' = 2.0$, and SNR is 0 dB, 10 dB and 20 dB. It can be concluded from Fig. 1 that the detection performance will be improved when $|\rho_h - \rho_v|$ is larger or the noise power is smaller.

The detection performance is analyzed by comparing the ROC curves between the method proposed in this paper (method 1) with the method in [4] (method 2). When JSR is 30 dB, SNR is 20 dB, and μ' is 2.0, the comparing result is shown in Fig. 2. It is obvious that the target detection performance of the method 1 is better than the method 2 in strong active jamming background.

4 Conclusion

The target detection method based on polarization information is studied in this paper. Based on the analysis of the polarization characterization of the received signals, a new method of target detection based on the difference of the polarization ratios of the matched filter outputs is given. The major advantage of this method is that the influence of the active jamming existed in traditional detection method is avoided. The performance of the detection method is analyzed by simulation experiment.

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