EVALUATION OF THE ABILITY OF TARGET DETECTION ON THE BACKGROUND CLUTTER USING THE STANDARD DEVIATION OF POLARIZATION PARAMETERS

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ABSTRACT.

The paper proposed a method of target detection on the background clutter using the standard deviation (STD) of polarimetry parameters. The authors conducted the examination, evaluation and comparison of the detection abilities of radar target models on the background clutter using the STD of ellipticity coefficient K and of the degree of polarization DoP. The results showed that the detection probability of the target Swerling 0 is better than other targets when using the STD of K and DoP. It is also found that the probability of target detection using the STD of K is higher than using the STD of DoP. From that results, it can be proposed the type of detection parameters suitable for each type of target model.

1. Introduction

Today scientists have recognized the effectiveness that data from polarimetric radar gives to marine applications and operations, such as: target detection on the sea surface [1, 2, 3], detection of metal targets on the sea surface [4, 5], monitoring oil spills on the sea surface [6]. In the problem of detecting targets on the background clutter, research results have shown that polarization measurements can be used effectively to detect targets on the background clutter.

In the polarimetric parameters used for the problem of detecting targets on the background surface, not many works have used the STD of polarization parameters. From experimental results with the detection of "polarization trace" effect, performed by Козлов А.И., Татаринов В.Н [7], [8], [9], [10] (Table 1, in which the target is a metallic pipe with the height l =1.5 m, and a diameter of 0.05 m at a distance of 1.5÷1.6 km on the sea surface) showed that in addition to the difference of the average *K* coefficient in the case of the sea surface without of a radar object and the case of compound object (sea surface plus man-made small-scale object), there is also a strong change in the variance of the ellipticity coefficient *K* between two cases. In particular, in the case of the sea surface without of a radar object, the variance of *K* varies from 0.23 to 0.56 depending on the wave conditions, whereas in the case of compound object, the variance of *K* varies from 0.033 to 0.125 with the same sea conditions. This experimental results shows that it is possible to use both the ellipticity coefficient *K* and the variance of *K* in the problem of detecting (or distinguishing) the target on the background surface.

Due to the fluctuation of the reflected signal from the background clutter, the polarization parameters derived from these signals are also random and fluctuate depending on the nature of the target and the background. The paper proposes an algorithm to use the standard deviation of the ellipticity coefficient *K* (*K*-STD) and the standard deviation of *DoP* (DoP-STD) in the problem of detecting targets on the background surface, especially on the sea surface. The layout of the article is as follows: part 2 gives an overview of the ellipticity coefficient *K* and the degree of polarization DoP; part 3 examines the ability to detect the radar target models Swerling using the STD of polarization parameters *K* and *DoP*; part 4 performs the comparison of the detection quality using K-STD and DoP-STD in the problem of target detection on the background clutter, part 5 is the conclusion.

Table 1.

Experimental results of ellipticity coefficient K on the sea surface [7]

Object	Wave height	Mean K, m_K	Variance of K, σ_K
Sea surface	≈ 0.2 m	$\langle K \rangle = -0,2 \div 0,1$	$\sigma_K = 0,23$
Object on the sea surface	≈ 0.2 m	$\langle K \rangle = -0.8$	$\sigma_K = 0.07 \div 0.08$
Sea surface	≈0.4÷0.5 m	$\langle K \rangle = 0$	$\sigma_K = 0.26$
Object on the sea surface	≈ 0.5 m	$\langle K \rangle = -0.75$	$\sigma_K = 0.033$
Sea surface	≈1.2÷1.5 m	$\langle K \rangle = 0$	$\sigma_K = 0.56$
Object on the sea surface	≈1.2÷1.5 m	$\langle K \rangle = -0.7$	$\sigma_K = 0.11 \div 0.125$

2. Statistical characteristics of K and DoP

a. Ellipticity coefficient

It is assumed that the transmitted signal (T_x) is a plane uniform right hand circular polarization (RHCP) E_R, which is presented by the Jones vector in Cartesian coordinate system [11]. The signals, received simultaneously from 2 orthogonal polarimetric channels, are expressed by quadrature components E_{Lcos} (E_{Lsin}) and E_{Rcos} (E_{Rsin}) as follow:

$$E_L(t) = \sqrt{\left[E_{L\cos}(t)\right]^2 + \left[E_{L\sin}(t)\right]^2}$$

$$E_R(t) = \sqrt{\left[E_{R\cos}(t)\right]^2 + \left[E_{R\sin}(t)\right]^2} \qquad (1)$$

If the received signals are scattered from the complex object (target and background), the quadrature components of received signal are:

$$\begin{aligned} E_{L\cos}(t) &= E_{L\cos.sig}(t) + E_{L\cos.\mathrm{int}}(t); \\ E_{L\sin}(t) &= E_{L\sin.sig}(t) + E_{L\sin.\mathrm{int}}(t); \\ E_{R\cos}(t) &= E_{R\cos.sig}(t) + E_{R\cos.\mathrm{int}}(t); \\ E_{R\sin}(t) &= E_{R\sin.sig}(t) + E_{R\sin.\mathrm{int}}(t). \end{aligned} \qquad (2)$$

where E_{int}(t) – the reflected signals from background clutter; E_{sig}(t) – the reflected signals from target.

The orthogonal polarimetric components of received signal:

$$\begin{aligned} E_L(t) &= \sqrt{\left[E_{L\cos.sig}(t) + E_{L\cos.\mathrm{int}}(t)\right]^2 + \left[E_{L\sin.sig}(t) + E_{L\sin.\mathrm{int}}(t)\right]^2} \\ E_R(t) &= \sqrt{\left[E_{R\cos.sig}(t) + E_{R\cos.\mathrm{int}}(t)\right]^2 + \left[E_{R\sin.sig}(t) + E_{R\sin.\mathrm{int}}(t)\right]^2}. \end{aligned} \qquad (3)$$

The absolute value of the circular polarization ratio is calculated as follows [11]:

$$P^{RL}(t) = \frac{E_R(t)}{E_L(t)} = \frac{\sqrt{\left[E_{R\cos.sig}(t) + E_{R\cos.\mathrm{int}}(t)\right]^2 + \left[E_{R\sin.sig}(t) + E_{R\sin.\mathrm{int}}(t)\right]^2}}{\sqrt{\left[E_{L\cos.sig}(t) + E_{L\cos.\mathrm{int}}(t)\right]^2 + \left[E_{L\sin.sig}(t) + E_{L\sin.\mathrm{int}}(t)\right]^2}} \qquad (4)$$

Following [12] the ellipticity coefficient is then can be calculated:

$$K(t) = \frac{1 - \left|\dot{P}^{RL}(t)\right|}{1 + \left|\dot{P}^{RL}(t)\right|} \qquad (5)$$

b. Degree of polarization

We consider that a target with deterministic polarization scattering matrix (PSM) is being illuminated by polarimetric radar, which has the ability of dual-polarization simultaneous reception (i.e., horizontal and vertical reception). The radar returns also include clutter signals surrounding the target echoes. Specially, the clutter in the main beam of the radar is mainly considered in this paper. There upon, the radar return corresponding to the range cell that the target exists can be established as the following model [13]:

$$H_1 : x = Sh_t a + c + n \qquad (6)$$

$$H_0 : x = c + n \qquad (7)$$

where H_1 denotes the target-present hypothesis, S is the 2 × 2 PSM of the target, which represents the polarization change of the transmitted signal; h_t is the 2 × 1 polarization Jones vector of the transmitted electromagnetic wave; a includes the transmitted radar waveform. The second term in the right side of Equation (6) represents the clutter signals. n is the noise in each polarimetric channel. We assume that the target exists in only one range cell. Then in other range cells, the signal model satisfies target-free hypothesis H_0.

Then, the measured data x in H_0 and H_1 case follows the bivariate complex Gaussian distribution with zero means [14]:

$$f_{H_0}(x) = \frac{1}{\pi^2 |\Sigma|} \exp\left(-x^H \Sigma^{-1} x\right) \quad (8)$$

$$f_{H_1}(x) = \frac{1}{\pi^2 |\Sigma|} \exp\left\{-(x-s)^H \Sigma^{-1} (x-s)\right\} \quad (9)$$

where ^{H} denotes the Hermitian transpose, Σ is the covariance matrix, and |Σ| is the determinant of Σ; the mean vector of x is defined as, $s \triangleq E(x) = Sh_s a$ and $\Sigma = E\left[(x-s)(x-s)^H\right]$.

As we know, the degree of polarization can be used to characterize the polarization state of the partially polarized waves. We can obtain this parameter from the Stokes vector or polarization covariance matrix. The latter is considered in this paper. Then, the DoP p can be defined in [15] as:

$$DoP \triangleq \frac{\sqrt{tr(\Sigma)^2 - 4|\Sigma|}}{tr(\Sigma)} = \frac{\eta_2 - \eta_1}{\eta_2 + \eta_1} \quad (10)$$

where tr(Σ) denotes the trace of Σ, η_1 and η_2 ($\eta_2 \geq \eta_1$) are the eigenvalues of Σ. Since we have no prior knowledge about the covariance matrix in real application, it should be estimated from the measured data.

According to the definition of the polarization covariance matrix (PCM) in [16], the estimation of the PCM can be generated from a set of observation samples $x_1, x_2, ..., x_N$ as follows:

$$\hat{\Sigma} \triangleq \frac{1}{N} \sum_{k=0}^{N-1} x_k x_k^H \quad (11)$$

where N is the integrated number of samples. If the eigenvalues of $\hat{\Sigma}$ are $\hat{\eta}_1, \hat{\eta}_2$, then the sample estimate of the DoP is defined as:

$$D\hat{o}P \triangleq \frac{\hat{\eta}_1 - \hat{\eta}_2}{\hat{\eta}_1 + \hat{\eta}_2} \quad (12)$$

In order to solve the problem of target detection using polarimetric parameters, it is necessary to use a statistical method based on the difference between the probability density function (PDF) of the reflected signal from the background clutter and of the total signal reflected from target and background. These probabilistic models are presented in the [17].

3. Examination of the detection ability of radar target models using the standard deviation of polarimetric parameters

In this section, the simulation of the ability to detect target models Swerling has done using the standard deviation of the polarization parameters: *K* and *DoP*. The parameters of three targets model Swerling 0 such as parameters *K*, *DoP*, range and radar cross section (RCS) are given on Table 2.

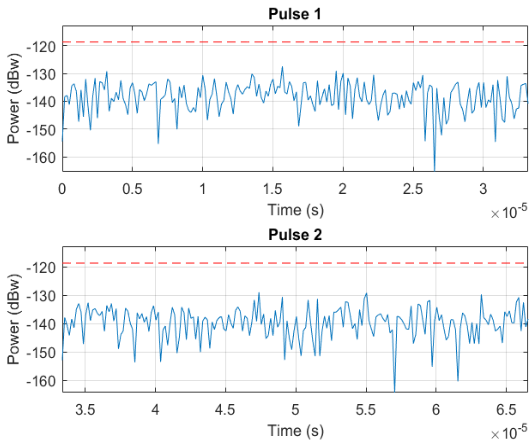
Table 2.

Parameters of targets

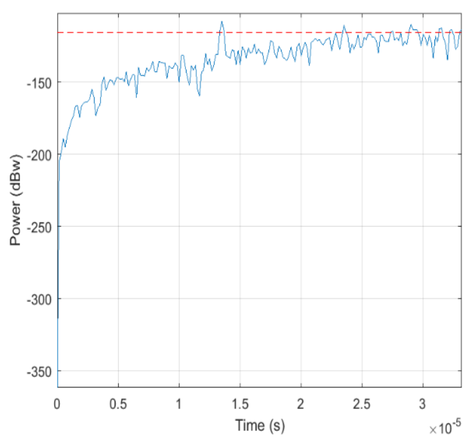
	Target 1	Target 2	Target 3
Range (m)	2024,66	3518,63	3845,04
K	0,82	-0,75	-0,98
DoP	0,18	0,28	0.71
RCS (m^2)	0,5	0,1	0,7

Firstly, calculate *K* by the equation (5) and *DoP* according to the equation (12), then calculate the standard deviation of *K* and *DoP* in each radar cell using Montecarlo method with N=1000. The simulation is performed independently of each value of RCS.

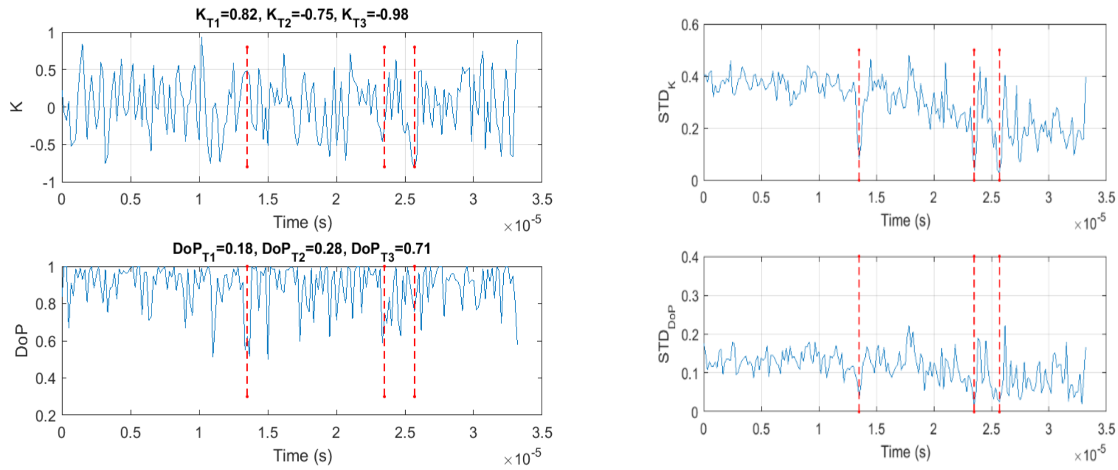
Fig 1 shows the simulation results of the ability to detect targets based on parameters K and DoP (Fig.1c) as well as based on the standard deviation of K, σ_K and standard deviation of DoP, σ_{DoP} (Fig.1d). Fig.1a depicts the reflected signal after each pulse, Fig.1b describes the signal after coherent integration with N=10 and using sensitivity time control (STC). Fig.1c are the estimated of *K* and *DoP* over time. Fig.1d are the estimated of σ_K and σ_{DoP} . The target position is located at the range marked with a dashed line on Fig.1c, d.



a



b



c d

Figure 1. a. Reflected signal; b. Signal after coherent integration N=10 and using STC; c. Values of K và D; d. STD of K and DoP

In addition to the three target locations is the background clutter. Fig.1c shows that the target's polarization parameters change due to the effect of background clutter and are different from their true values. Specifically, for target 1, the measured *K* value is $\hat{K} = 0.5$ compared to the true value $K = 0.82$, target 2 has $\hat{K} = -0.48$ compared to the true value $K = -0.75$, target 3 has $\hat{K} = -0.4$ and $K = -0.98$. Similarly, target 1 has a measured DoP, $D\hat{o}P = 0.6$ compared to the true value $DoP = 0.18$, target 2 has $D\hat{o}P = 0.7$ and $DoP = 0.28$, target 3 has $D\hat{o}P = 0.83$ and $DoP = 0.71$. So when using *K* or *DoP* parameters, the values of these ones are mixed with the values of background clutter, which lead to the higher probability of false alarm. In contrast, as shown in Fig1.d, it can be seen that the STD of *K* and *DoP* at the target position differs from those with only background clutter. For example, for background clutter, σ_K varies from 0.35 to 0.45, while $\sigma_K \approx 0.1$ for target 1, $\sigma_K \approx 0.11$ for target 2 and $\sigma_K \approx 0.12$ for target 3. Similarly, the standard deviation of DoP for background clutter $\sigma_{DoP} = 0.1 \div 0.15$ meanwhile $\sigma_{DoP} = 0.05$ for target 1, $\sigma_{DoP} = 0.06$ for target 2 and $\sigma_{DoP} = 0.07$ for target 3.

To assess the quality of detection with the radar target models Swerling using STD of the parameters *K* and *DoP*, 1000 independent tests to calculate σ_K and σ_{DoP} for target 1 have been performed at each value of RCS. We give RCS values gradually increasing step by step from 0 to 1 m^2. The probability of detection P_D is calculated by the number of times the measured STD (σ_K, σ_{DoP}) is less than the detection threshold on the total number of tests. The detection threshold by the STD is calculated based on the probability of false alarms when only background clutter is present. The target parameters are given in Table 2. The comparative results of the probability of target detection based on the STDs of K and DoP with the Swerling target models have been shown in Fig 2 and Fig 3.

Fig 2 shows that P_D for the target Swerling 0 is the best when σ_{DoP} is used. Specifically, if RCS of the target is greater than 0.3 m^2, $P_D \approx 1$ for the target model Swerling 0. P_D for target models Swerling 3, 4 are worse than for the target model Swerling 0 but better than for the target models Swerling 1, 2. For example, with $P_{FA} = 10^{-6}$ (Fig.2d), if $RCS = 0.6m^2$ then $P_D = 0.62$ for target model Swerling 1; $P_D = 0.73$ for target model Swerling 2; $P_D \approx 0.85$ for target model Swerling 3, 4; and $P_D = 1$ for target model Swerling 0. If $RCS \geq 0.8m^2$ then $P_D = 1$ for all of models Swerling.

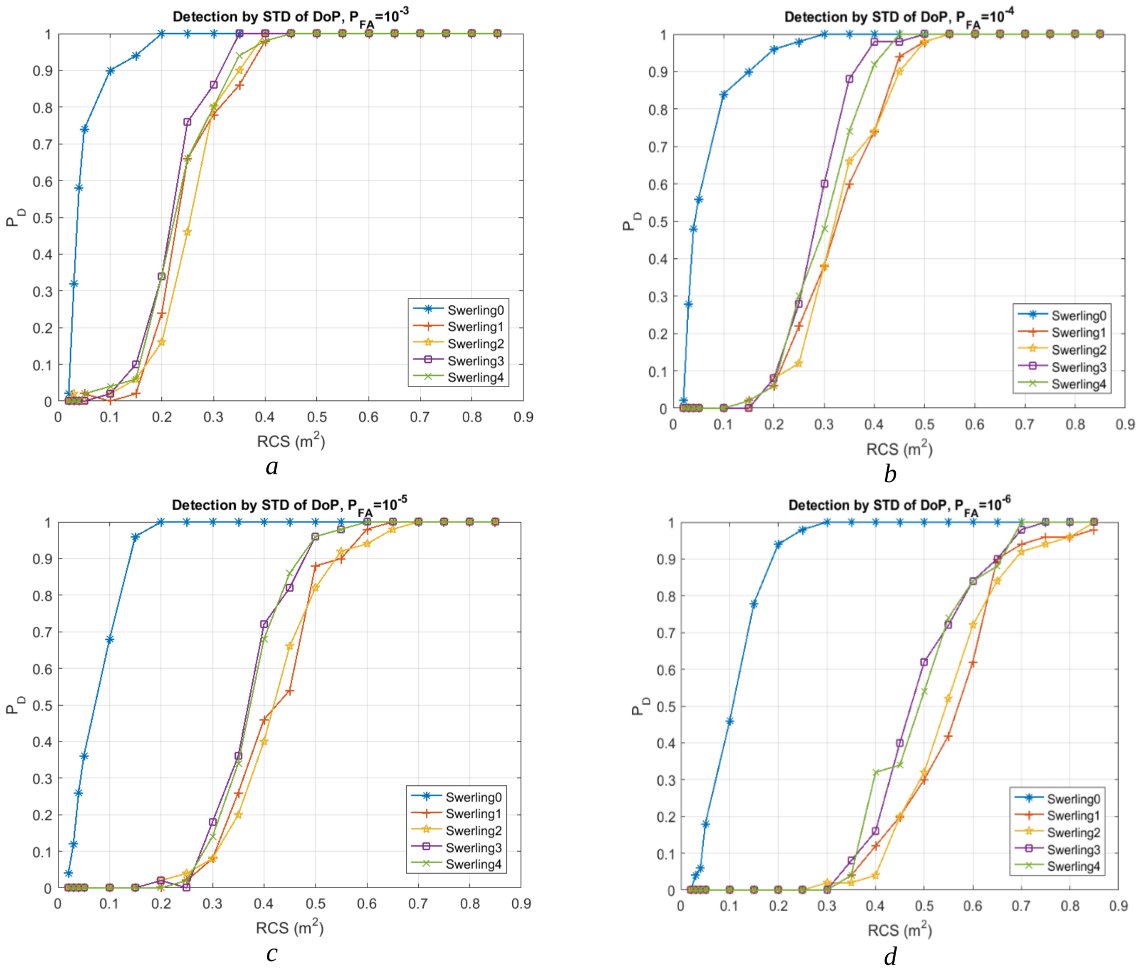
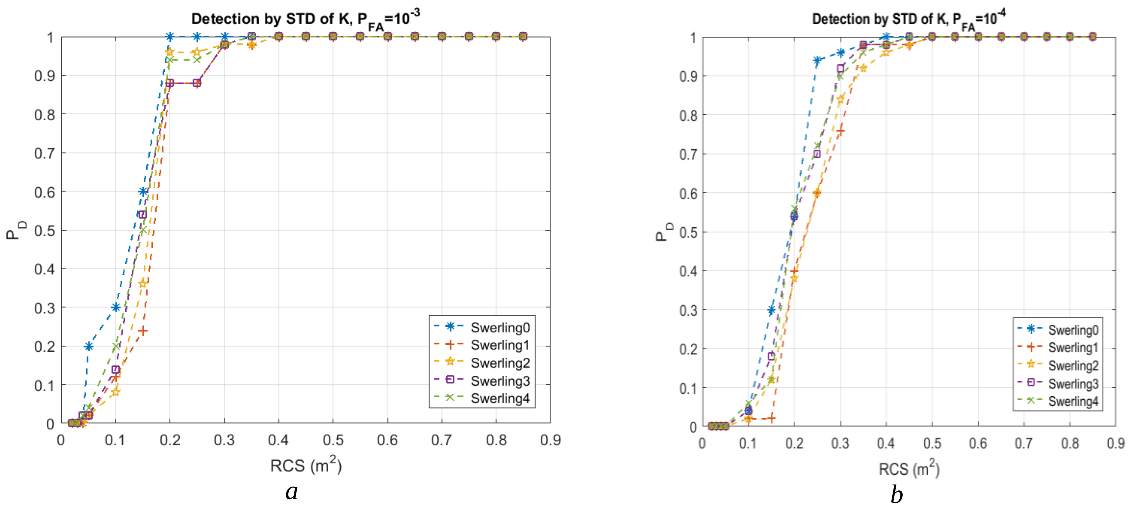
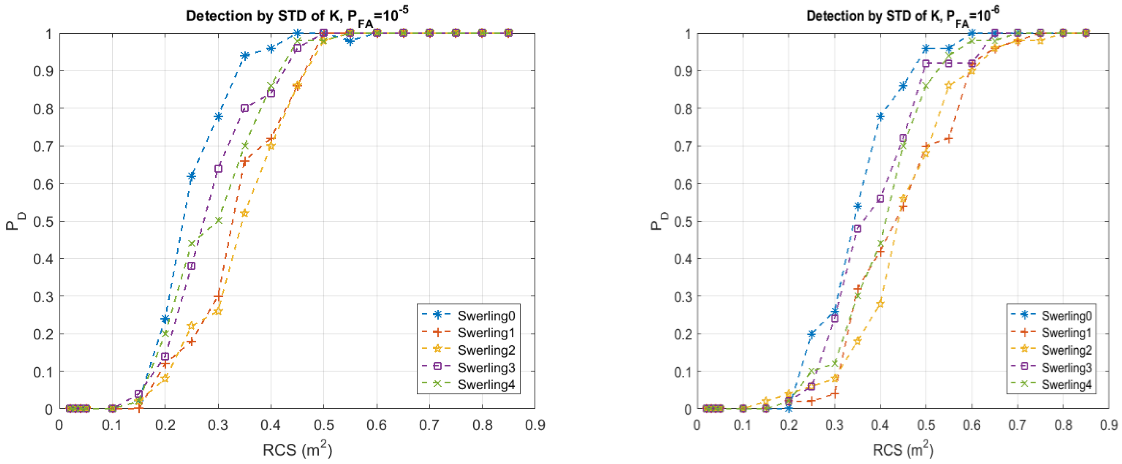


Figure 2. The comparison of quality of target detection based on STD of DoP with different P_{FA}

Fig 3, corresponding the case of using the STD of *K*, shows that the P_D for all target models Swerling are nearly equal. Specifically, the case with $P_{FA} > 10^{-5}$, if $RCS \geq 0.4 m^2$ then $P_D \approx 1$ for all target models. P_D increased suddenly from 0 to 1 when RCS changed from 0.1 m^2 to 0.4 m^2.

When comparing the quality of detecting the target models Swerling, it can be seen that, P_D for detection of target models Swerling 0 is best using σ_{DoP}, it is good for target models Swerling 3, 4 and is worst for target models Swerling 1, 2.





c *d*

Figure 3. The comparison of quality of target detection based on STD of K with different P_{FA}

4. The comparison of quality of target detection using the standard deviations of *K* and *DoP*

The comparison process is performed when simulating the ability to detect a same target model Swerling but using two different detection parameters σ_K and σ_{DoP}. The comparison results are shown in Fig 4.

Fig 4 showed that, generally the detection quality of target model Swerling using σ_K was better than using σ_{DoP}. However, for the target model Swerling 0, the method using σ_{DoP} gave good results superior to the method using σ_K and better than with target models Swerling 1, 2, 3, 4.

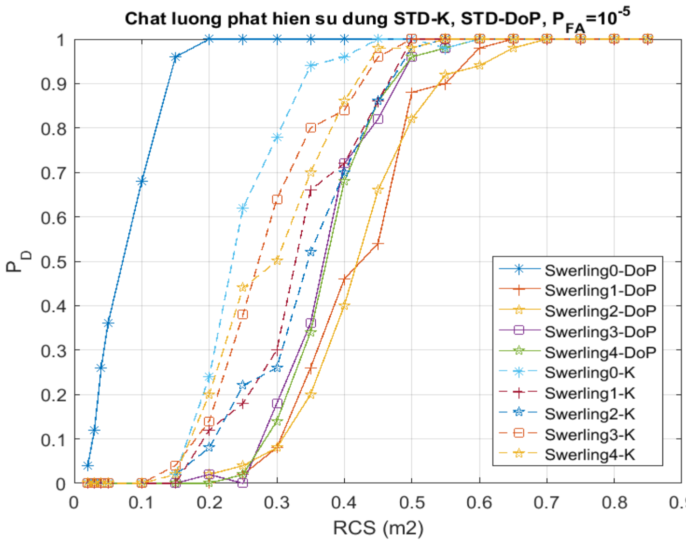


Figure 4. The comparison of quality of target detection using the standard deviations of K and DoP

5. Conclusion

The paper examined the ability to detect targets on the background clutter based on the standard deviation of polarization parameters: *K* and *DoP* with different target models Swerling. The results show that when using the K-STD method, the probability of detection for the target models Swerling is nearly equal. Meanwhile if the DoP-STD method is used, the probability of detection for the target model Swerling 0 is better than for the target models Swerling 1,2,3,4. The quality of target detection by K-STD method is also better than using DoP-STD method. Based on the results of the research, it is possible to propose the appropriate detection parameters for each radar target model to increase the ability to detect targets on the background clutter.

References

[1] Peng Wu, Jun Wang en Wenguang Wang, „A Novel Method of Small Target Detection in Sea Clutter," International Scholarly Research Network ISRN Signal Processing, vol. 33, nr. 4, pp. 816-822, 2011.

[2] Novak L. M en Sechtin M. B, „Studies of target detection algorithms that use polarimetric radar data," IEEE Trans. on Aerosp. Electron. Syst, vol. 25, nr. 2, pp. 150-165, Mar, 1989.

[3] Pastina D, Lombardo P en Bucciarelli T, „Adaptive polarimetric target detection with coherent radar. Part I: Detection against Gaussian background," IEEE Trans. on Aerosp. Electron. Syst, vol. 1, nr. 4, pp. 1194-1206, 2001.

[4] F. Nunziata, M. Migliaccio en C. E. Brown, „Reflection symmetry for polarimetric observation of

man-made metallic targets at sea," IEEE J. Ocean. Eng, vol. 37, nr. 3, p. 384–394, Jul. 2012.

[5] D. Velotto, F. Nunziata, M. Migliaccio en S. Leh, „Dual polarimetric TerraSAR-X SAR data for target at sea observation," IEEE Geosci. Remote Sens. Lett, vol. 10, nr. 5, p. 1114–1118, Sep. 2013.

[6] M. J. Collins, M. Denbina, B. Minchew en C. E. Jones, „On the use of simulated airborne compact polarimetric SAR for characterizing oil–water mixing of the deepwater horizon oil spill," IEEE J. Sel. Topics Appl. Earth Observ. Remote Sens, vol. 8, nr. 3, p. 1062–1077, Mar. 2015.

[7] Козлов А.И., Татаринов В.Н., Татаринов С.Н. en Кривин Н.Н., „Поляризационный след при рассеянии электромагнитных волн составными объектами," Научный вестник МГТУ ГА. Серия «Радиофизика и радиотехника», vol. 189, nr. 12, pp. 66-72, 2013.

[8] Кривин Н.Н., Козлов А.И. en Татаринов, С.В, „Поляризационные инварианты в задачах обнаружения малоразмерных РЛО," Научный вестник МГТУ ГА. Серия «Радиофизика и радиотехника», 2011, №171, С. 14-19.

[9] Ligthart L., Tatarinov V.N., Tatarinov S.N. en Pusone E., „An effective polarimetric detection of small-scale man-made radar objects on the sea surface," Microwaves Radar and Wireless Communications, MIKON-2002. 14th International Conference on Publication Year, vol. 2, pp. 677 - 680.

[10] Кривин Н.Н. , Поляризационный след и поляризационный контраст малоразмерных радиолокационных объектов, дисс. канд. тех. наук: 05.12.04, Томск, ТИАСУР, 2015, 111 с.

[11] Tatarinov V.N., Tatarinov S.N. en Ligthart L.P., An Introduction to Radar Signals Polarization Modern Theory, Tomck, Russia: Vol1. Publ. House of Tomsk State University, 380 p, 2006.

[12] Поздняк С.И en Мелитицкий В.А, Введение в статистическую теорию поляризации радиоволн, М: Сов.радио, 1974, 480 с.

[13] J. J van Jyl en F. T. Ulaby, Scattering matrix representation for simple targets, Norwood MA: Artech House, 1990.

[14] Goodman, N. R, „Statistical analysis based on a certain multivariate complex Gaussian distribution (an introduction)," The Annals of Mathematical Statistics, vol. 34, p. 152–177, 1963.

[15] Wolf E, „Coherence properties of partially polarized electromagnetic radiation," II Nuovo Cimento, vol. XIII, nr. 6, pp. 1165-1181, 1959.

[16] Born, M en Wolf. E, Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light, Cambridge, U.K: Cambridge Univ. Press, 1999.

[17] Поздняк С.И. en Мелитицкий В.А., Введение в статистическую теорию поляризации радиоволн, М.: Сов.радио, 1974, 480 с.

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МЕТОДОЛОГИЧЕСКИЕ ОСНОВЫ ИНЖЕНЕРНО-ЭКОЛОГИЧЕСКИХ ВОДОХОЗЯЙСТВЕННЫХ ОБЪЕКТОВ

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АННОТАЦИЯ.
В соответствии основных принципов охраны окружающей среды (ОПС) в статье рассматривается методология процедуры проведения ОВОС, инженерно-экологических изысканий, экологического контроля на предприятиях, государственной экологической экспертизы федерального и регионального уровней.

SUMMARY.
In compliance of the basic principles of environmental protection (OPS) in article the methodology of the procedure of carrying out EIA, engineering-ecological researches, environmental control at the enterprises, the state environmental assessment of federal and regional levels.

Ключевые слова: природные среды, планируемая хозяйственная деятельность (ПХД), ОВОС, экология, мониторинг, изыскания, экспертиза, контроль.