Generalized Optimization of Polarimetric Contrast Enhancement

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I. Introduction

The Optimization of Polarimetric Contrast Enhancement (OPCE) is one of important problems in radar polarimetry. The traditional OPCE is to choose optimal polarization states for enhancing a desired target versus an undesired target/clutter. The contrast enhancement enables us to discriminate or distinguish the desired target from background or from the undesired target [1].

In this paper, a generalized OPCE (GOPCE) is proposed. For the GOPCE problem, we need not only to find three coefficients such that the ratio of two factors associated with the desired target and clutter is maximal, but also to find optimal polarization states such that the received power ratio of the target and clutter is maximal. Both the factors consist of three parameters, i.e., the Cloude entropy [2] and two special similarity parameters [3]. The optimal coefficients of the GOPCE are obtained by solving an eigenvalue problem. Using an example, we demonstrate that the GOPCE can be employed for detecting roads in a forest area by using polarimetric SAR data.

II. Similarity Parameter

In this section, we present two special similarity parameters which will be used in Section 3.

For the problems of target classification and target recognition in radar polarimetry, one problem is how to analyze characteristics of a radar target. The similarity parameter [3] may be employed for extracting single reflected and double reflected contributions of a target. Let

$$[S] = \begin{bmatrix} s_{HH} & s_{HV} \\ s_{VH} & s_{VV} \end{bmatrix} \quad (1)$$

denote a target scattering matrix in a linear horizontal (H) and vertical (V) polarization base, and let ψ denote the orientation angle of the target, which is easy to calculate due to Huynen’s decomposition, we may rotate the target to a special position, where its orientation angle equals zero:

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$$\left[S^0\right]=\left[J(-\Psi)\right]\cdot\left[S\right]\cdot\left[J(\Psi)\right]=\begin{bmatrix} s_{HH}^0 & s_{HV}^0 \\ s_{VH}^0 & s_{HH}^0 \end{bmatrix}, \qquad (2)$$

where $\left[J(\Psi)\right]=\begin{bmatrix} \cos\Psi & -\sin\Psi \\ \sin\Psi & \cos\Psi \end{bmatrix}$.

According to the definition of the similarity parameter [3], one easily calculates following typical similarity parameters as follows.

i) The similarity parameter between an arbitrary scattering matrix [S] and a plane is given by:

$$r_1 = r([S], diag(1,1)) = \frac{\left|s_{HH}^0 + s_{VV}^0\right|^2}{2\left(\left|s_{HH}^0\right|^2 + \left|s_{VV}^0\right|^2 + 2\left|s_{HV}^0\right|^2\right)}. \qquad (3)$$

This parameter is related to the measurement of single reflections from a target.

ii) The similarity parameter between an arbitrary scattering matrix [S] and a dihedral is given by:

$$r_2 = r([S], diag(1,-1)) = \frac{\left|s_{HH}^0 - s_{VV}^0\right|^2}{2\left(\left|s_{HH}^0\right|^2 + \left|s_{VV}^0\right|^2 + 2\left|s_{HV}^0\right|^2\right)}. \qquad (4)$$

This parameter is related to the measurement of double reflections from a target.

III. The Generalized OPCE

Let TA and TB denote two kinds of targets, and let $\left[\overline{K}(TA)\right]$ and $\left[\overline{K}(TB)\right]$ be the average Kennaugh matrices of TA and TB, respectively. For the traditional OPCE problem, we need to find the optimal polarization states $\mathbf{g}=(1,\ g_1,\ g_2,\ g_3)^t$ (here t demotes the transpose) and $\mathbf{h}=(1,\ h_1,\ h_2,\ h_3)^t$ for maximizing the power ratio of TA and TB, i.e,

$$\textit{maximize} \quad \frac{\left[\overline{K}(TA)\right]\mathbf{g}\bullet\mathbf{h}}{\left[\overline{K}(TB)\right]\mathbf{g}\bullet\mathbf{h}}\ , \qquad (5)$$

$$\textit{subject to:}\quad g_1^2+g_2^2+g_3^2=1,$$

$$h_1^2+h_2^2+h_3^2=1.$$

Using an iteration algorithm [1], one easily obtains the optimal polarization states for the above problem.

In the GOPCE problem, the mathematical model is to solve

$\mathbf{x} = (x_1, x_2, x_3)^t$, $\mathbf{g}$ and $\mathbf{h}$ for the following optimization:

$$\textit{maximize} \quad \frac{\sum_{TA}\left[\sum_{i=1}^{3} x_i r_i(TA)\right]^2}{\sum_{TB}\left[\sum_{i=1}^{3} x_i r_i(TB)\right]^2} \times \frac{\left[\overline{K}(TA)\right]\mathbf{g}\bullet\mathbf{h}}{\left[\overline{K}(TB)\right]\mathbf{g}\bullet\mathbf{h}}\ , \tag{6}$$

$$\textit{subject to:} \quad g_1^2 + g_2^2 + g_3^2 = 1,$$

$$h_1^2 + h_2^2 + h_3^2 = 1,$$

$$x_1^2 + x_2^2 + x_3^2 = 1,$$

where r_1 and r_2 are defined by (3) and (4), respectively. $r_3 = H$ denotes the polarization entropy [2]. For the above GOPCE problem (6), the optimal polarization states $\mathbf{g}$ and $\mathbf{h}$ are the same as those of the traditional OPCE problem (5) which can easily be obtained by the method of [1]. Now we only need to find the optimal coefficients x_i ($i = 1, 2, 3$). Obviously, they can be obtained by solving the following eigenvalue problem

$$\sum_{TA}\left[R(TA)\right]\mathbf{x} = \lambda \sum_{TB}\left[R(TB)\right]\mathbf{x}, \tag{7}$$

where $\left[R(TA)\right] = \left[r_i(TA)\, r_j(TA)\right]_{3\times 3}$ and $\left[R(TB)\right] = \left[r_i(TB)\, r_j(TB)\right]_{3\times 3}$. It is easy to prove that the eigenvector associated with the maximum eigenvalue is the optimal coefficient vector $\mathbf{x} = (x_1, x_2, x_3)^t$ of (6).

IV. Application and Conclusion

As an application, the GOPCE can be employed for detecting roads in a forest. Here, we use A NASA SIR-C/X-SAR L-band image of a forest area in Tian Shan (China) for validating the effectiveness of the GOPCE. Fig. 1 shows the span image of the forest. In black areas, trees have been felled. Select an area consisting of trees and an area where there have been no tree as TA and TB, respectively. Using the iteration algorithm [1], we obtain the optimal polarization states of the traditional OPCE problem as $\mathbf{g} = (1, -0.075, -0.997, -0.031)^t$ and $\mathbf{h} = (1, 0.132, 0.979, 0.155)^t$, and the corresponding power ratio is 114.993. Fig. 2 shows the received power image associated with the optimal polarizations. From this image, one easily finds a road below the largest black area, whereas it is not clear in Fig. 1.

Solving (7), we obtain $\mathbf{x} = (-0.254,\ -0.312,\ 0.916)^t$. The corresponding total ratio of (6) equals 426.246. It is larger than the maximal power ratio of the traditional OPCE problem (5). After calculating $GP = \left[\sum_{i=1}^{3} x_i r_i\right]^2 \times [K]\mathbf{g} \bullet \mathbf{h}$ for all pixels, then we obtain a new image shown in Fig.3. In this image, all roads detected before becomes clearer. In addition, one can find a new road from the left side to the right side. Although this new detected road is not so clear in Fig. 3, it can hardly found from Fig. 1 and Fig. 2. Therefore, the GOPCE is more effective than the traditional OPCE.

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References

[1] J. Yang, et al., *IEEE Trans. Geosci. Remote Sensing*, **38**, 965-971, 2000.

[2] S.R. Cloude and E. Pottier, *IEEE Trans. Geosci. Remote Sensing*, **35**, 68-78, 1997.

[3] J. Yang, et al., *Electron. Lett.*, **37**, 193-194, 2001.

Fig. 1 The span image of a forest area, Tian Shan, China

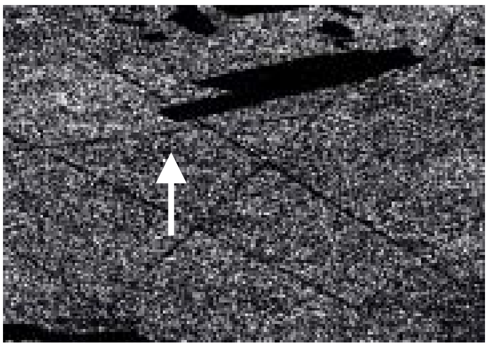

Fig. 2 The received power image under the optimal polarization states

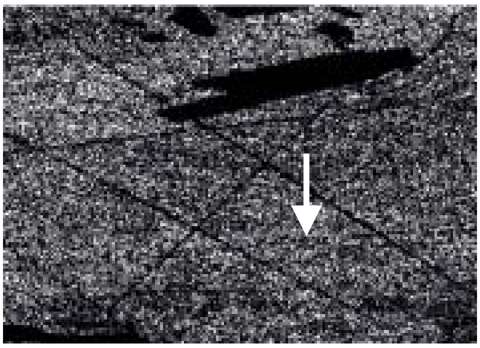

Fig. 3 The image of $GP = \left[\sum_{i=1}^{3} x_i r_i\right]^2 \times [K]\mathbf{g} \bullet \mathbf{h}$