Polarimetric Classification of Trees

Yoshio Yamaguchi *, Makoto Murase *, Hiroyoshi Yamada *, Jian Yang **
* Dept. of Information Engineering, Niigata University, JAPAN
yamaguch@ie.niigata-u.ac.jp
** Dept. of Electronic Engineering, Tsinghua University, CHINA

Abstract

Radar Polarimetry is now indispensable tool for monitoring the earth cover. The advantage of using vector nature of electromagnetic wave is the abundant information on amplitude, phase and the relation pertaining to target. In this paper, we tried to retrieve useful index for classifying trees, forests, vegetations. The index is used polarimetric correlation coefficient derived by the elements of Sinclair scattering matrix. It is shown that correlation coefficient defined by the circular polarization basis serves to distinguish conifer tree and broadleaf tree.

1. Scattering matrix and correlation coefficient

The Sinclair matrix [S(HV)] is defined as

$$\boldsymbol{E}^s = \begin{bmatrix} E_H^s \\ E_V^s \end{bmatrix} = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} \begin{bmatrix} E_H^t \\ E_V^t \end{bmatrix} = [\boldsymbol{S}(HV)]\ \boldsymbol{E}^t \tag{1}$$

where, $\boldsymbol{E}^t$ is the Jones vector of transmitted wave and $\boldsymbol{E}^s$ is scattered wave. The polarization basis is implied to be Horizontal (H) and Vertical (V) in this case. In the monostatic case, $S_{HV} = S_{VH}$ due to the reciprocity theorem.

In this HV basis case, the complex correlation coefficient between HH and VV channel can be constructed as,

$$\gamma_{HV} = |\,\gamma_{HV}\,| \qquad \gamma_{HV} = \frac{\langle S_{HH}\ S_{VV}^*\rangle}{\sqrt{\langle |S_{HH}|^2\rangle\langle |S_{VV}|^2\rangle}} \tag{2}$$

where < • > is ensemble averaging.

If the scattering matrix pertaining to a target is obtained by a fully polarimetric radar, it is possible to transform it into an arbitrary basis AB by

$$\begin{aligned} S_{AA} &= \frac{1}{1+\rho\rho^*}\left(S_{HH} + 2\,\rho\, S_{HV} + S_{VV} \right) \\ S_{AB} &= \frac{-\,j}{1+\rho\rho^*}\left(-\rho^* S_{HH} + (1-\rho\rho^*)\, S_{HV} + \rho S_{VV} \right) \\ S_{BB} &= \frac{1}{1+\rho\rho^*}\left(\rho^{*2} S_{HH} - 2\,\rho^* S_{HV} + S_{VV} \right). \end{aligned} \tag{3}$$

where ρ is the complex polarization ratio. Hence, Equation (3), applied to a circular polarization basis ($\rho = j$) , leads to

$$S_{LL} = \frac{1}{2}\left(S_{HH} - S_{VV} - 2\ jS_{HV} \right) = \frac{1}{2}\left(\alpha - j\beta \right) \tag{4}$$

$$S_{RR} = \frac{1}{2}\left(S_{HH} - S_{VV} + 2\ jS_{HV} \right) = \frac{1}{2}\left(\alpha + j\beta \right) \tag{5}$$

where $\alpha = (S_{HH} - S_{VV})$ and $\beta = (2\,S_{HV})$. If we assume trees area (forested field or vegetation field) showing azimuth symmetry [1] , (ie., $S_{HH}S_{HV}^* = S_{VV}S_{HV}^* = 0$) , α and β are found to be uncorrelated $(\alpha\,\beta^* = 0)$. Under this assumption, the correlation coefficient between S_{RR} and S_{LL} becomes,

$$\gamma_{LR} = |\,\gamma_{LR}\,| = \frac{\langle S_{LL}\ S_{RR}^*\rangle}{\sqrt{\langle |S_{LL}|^2\rangle\langle |S_{RR}|^2\rangle}} = \frac{\langle |\,\alpha\,|^2\rangle - \langle |\,\beta\,|^2\rangle}{\langle |\,\alpha\,|^2\rangle + \langle |\,\beta\,|^2\rangle} \tag{6}$$

$$\langle|\alpha|^2\rangle = [\langle|S_{HH}|^2\rangle - 2\ \mathrm{Re}(\gamma_{HV})\sqrt{\langle|S_{HH}|^2\rangle\langle|S_{VV}|^2\rangle} + \langle|S_{VV}|^2\rangle]$$
$$\langle|\beta|^2\rangle = [4\langle|S_{HV}|^2\rangle]$$

where γ_{LR} is real.

Moreover, the CO-POL Max polarization ratio are given by [2].

$$\rho_{cm1,2} = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \tag{7}$$

where $A = S^*_{HH}S_{HV} + S^*_{HV}S_{VV}$, $B = |S_{HH}|^2 - |S_{VV}|^2$ and $C = -A^*$. Substituting (7) in (3) yields the optimum polarization state basis. Thus, the optimum polarization correlation coefficient can be obtained by

$$\gamma_{OP} = |\gamma_{OP}| \qquad \gamma_{OP} = \frac{\langle S_{AA}\ S^*_{BB}\rangle}{\sqrt{\langle|S_{AA}|^2\rangle\langle|S_{BB}|^2\rangle}}\ . \tag{8}$$

Now, it is possible to choose any polarization basis. The candidate may be

- Linear polarization basis HV $\quad \gamma_{HV} = |\gamma_{HV}| \quad \gamma_{HV} = \dfrac{\langle S_{HH}\ S^*_{VV}\rangle}{\sqrt{\langle|S_{HH}|^2\rangle\langle|S_{VV}|^2\rangle}}$
- Circular polarization basis LR $\quad \gamma_{LR} = |\gamma_{LR}| = \dfrac{\langle S_{LL}\ S^*_{RR}\rangle}{\sqrt{\langle|S_{LL}|^2\rangle\langle|S_{RR}|^2\rangle}}$
- Optimum polarization states basis $\quad \gamma_{OP} = |\gamma_{OP}| \quad \gamma_{OP} = \dfrac{\langle S_{AA}\ S^*_{BB}\rangle}{\sqrt{\langle|S_{AA}|^2\rangle\langle|S_{BB}|^2\rangle}}$

2. Laboratory Experiment

Two small trees were set in anechoic chamber for radar targets as shown in Fig.1.

Broadleaf tree

Conifer tree

Fig.1 Photographs of trees used in experiment.

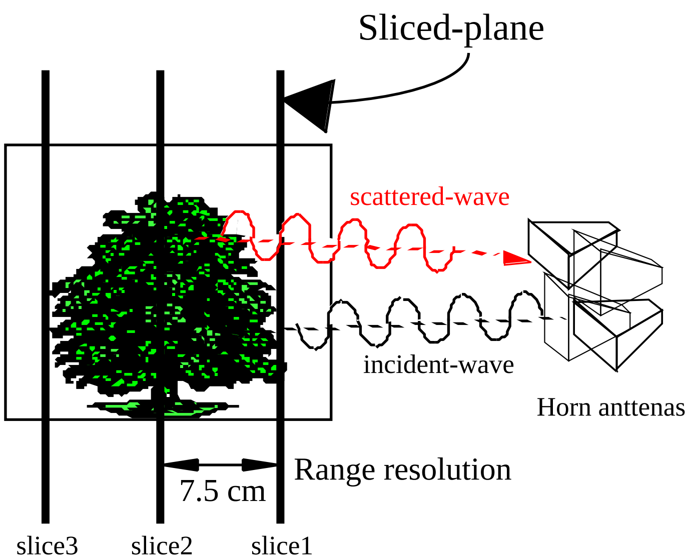


Fig.2 A geometry of sliced plane along range direction.

The first is broadleaf tree and the second one is conifer tree. A network analyzer was used to acquire scattering matrices from these trees. Since radar resolution can be chosen arbitrary by choosing the bandwidth of transmitting signal, we used 2 GHz bandwidth. This bandwidth results in range resolution of 7.5 cm, which covers entire range of tree width. This benefits us to retrieve scattering mechanism within the canopy. Therefore, it was possible to retrieve sliced plane the tree [3] as shown in Fig.2.

The polarimetric signa-ture of trees at sliced plane1 are shown Fig.3. It is seen the scattering behavior is different. The magnitude of correlation coefficient for trees are shown in Fig.4 As wave penetrates into canopy, the difference in correlation for both trees coincide each other (at slice2 and 3). However, the forefront magnitude is quite different for conifer and broadleaf trees. This fact is important for classifying trees.

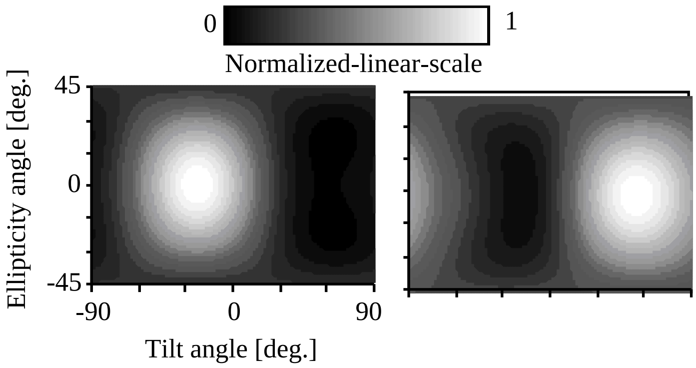


Fig3. Polarimetric signature of sliced plane1. Broadleaf tree (left), Conifer tree (right).

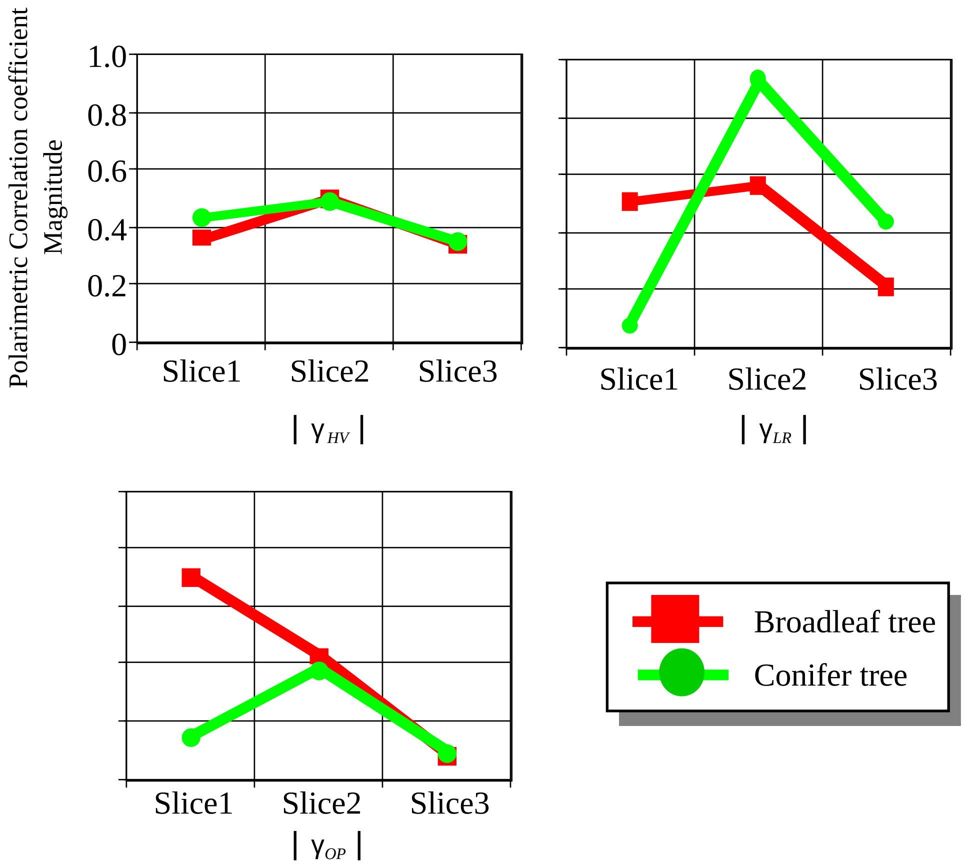
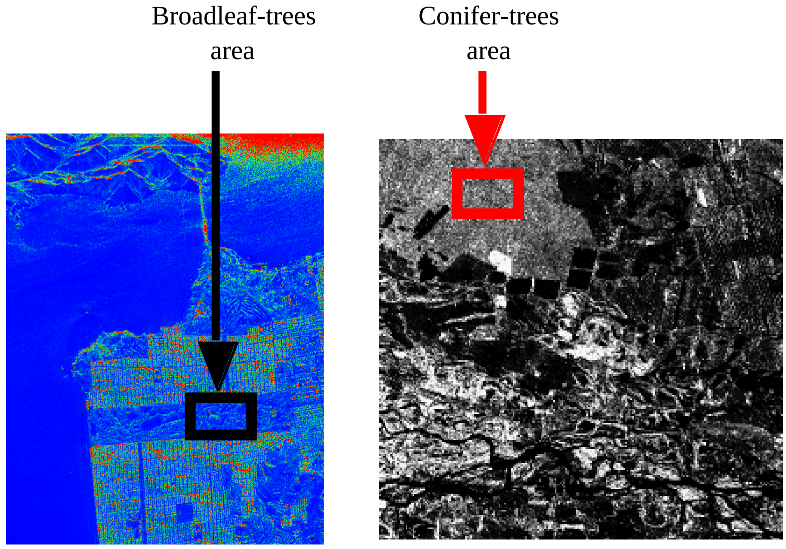


Fig.4 Magnitude of correlation coefficient of sliced plane along range direction.

3. POL-SAR data validation

Fig.5 shows the images of the Sanfrancisco (Broadleaf trees area) and Briatia (Conifer trees area). Since actual polarimetric SAR images is available, we applied these indices to confirm the validity. Fig.6 also shows $|\gamma_{HV}|$ and $|\gamma_{LR}|$ Sanfrancisco map. We calculated the polarimetric correlation coefficients for the selected area shown Fig.5. The results are listed in Table I and II. It is seen that the value of $|\gamma_{LR}|$ is much more dependent on tree types than $|\gamma_{HV}|$. This fact also supports the superiority of $|\gamma_{LR}|$ for classification of trees.



(a) (b)

Fig.5 POL-SAR data (a) Sanfrancisco, (b) Briatia.

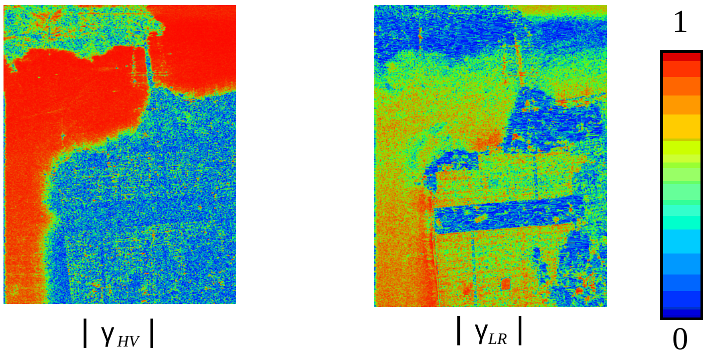


Fig.6 $|\gamma_{HV}|$, $|\gamma_{LR}|$ iamges (Sanfrancisco).

Table I Sanfrancisco (Broadleaf trees area).

	$\|\gamma_{HV}\|$	$\|\gamma_{LR}\|$	$\|\gamma_{OP}\|$
area1	0.176	0.384	0.457
area2	0.189	0.342	0.370
area3	0.221	0.261	0.290

Table II Briatia (Conifer trees area).

	$\|\gamma_{HV}\|$	$\|\gamma_{LR}\|$	$\|\gamma_{OP}\|$
area1	0.154	0.583	0.560
area2	0.177	0.664	0.627
area3	0.177	0.644	0.627

4. Conclusion

Although there are many polarimetric parameters to describe target characteristics, the proposed polarimetric correlation coefficient defined in the circular polarization basis seems good index at discriminating conifer tree and broadleaf tree. This fact was confirmed in a laboratory measurement and validated by actual POL-SAR images.

Acknowledgment

This work in part was supported by Grant in Aid for Scientific Research, Ministry of Education, Japan.

References

[1] S. V. Nghiem, S. H. Yueh, R. Kwok, and F. K. Li, “Symmetry properties in polarimetric remote sensing,” *Radio Sci.*, vol. 27, pp. 693-711, Sept. 1992.

[2] Boerner, W-M., W-L. Yan, A-Q. Xi and Y. Yamaguchi, “On the basic principles of radar polarimetry : the target characteristic polarization state theory of Kennaugh, Huynen’s polarization fork concept, and its Extension to the Partially Polarized Case,” *Proc. of the IEEE*, Special Issue on Electromagnetic Theory, vol. 79, pp. 1538-1550, Oct. 1991.

[3] M. Murase, Y. Yamaguchi, H. Yamada, “X-band polarimetric synthetic aperture radar imaging of a small tree,” *Proceedings of ISAP 2000*, vol. 3, pp. 1255-1258, Aug. 2000.