AUTOMATIC TARGET RECOGNITION METHOD BASED ON POLSAR IMAGES WITH CIRCULAR POLARIMETRIC BASIS CONVERSION

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ABSTRACT

Satellite-borne or aircraft-borne synthetic aperture radar (SAR) technique is useful for high resolution imaging analysis for terrain surface monitoring or surveillance, even in optically harsh environment. For surveillance application, there are various approaches for automatic target recognition (ATR) of SAR images aiming at monitoring unidentified ships or aircrafts. In addition, various types of analyses using full polarimetric data have been developed recently because it can provide significant information to identify structure of targets, such as vegetation, urban, sea surface areas. In this paper, the circular polarization basis conversion is adopted to improve the robustness especially to variation of target rotation angles. The experimental data, assuming the 1/100 scale model of X-band radar, demonstrate that our proposed method significantly improves an accuracy of target area extraction and classification, even in noisy or angular fluctuated situations.

Index Terms— Synthetic aperture radar(SAR), Polarimetric SAR, Automatic Target Recognition(ATR), Circular Polarization Basis

1. INTRODUCTION

Microwave radar is one of the most useful techniques for measuring ground terrain or sea surface, even in optically unclarity situations such as adverse weather or darkness. Synthetic aperture radar (SAR) is the most well-known microwave imaging method that has been applied to earth observation for environmental monitoring or for maritime security with regard to the identification of unidentified ships or aircraft, because it can provide high-resolution and complex-valued images. However, it is still difficult for an inexperienced operator to recognize targets within SAR imagery compared with optical images, because SAR images are generated by radio signals with wavelengths of the order of centimeters.

To address this issue, various types of automatic target recognition (ATR) approaches have been developed in recent years, which include machine learning methods such as neural networks [1] or support vector machine (SVM) [2]. In particular, there have been many reports stating that neural-network-based classification retains a certain level of accuracy in target recognition with SAR imagery. However, such approaches result in seriously degraded classification accuracy when the available SAR images are highly contaminated by random noise. To overcome this difficulty, we have previously proposed the ATR method based on a supervised self-organizing map (SOM) method, where the unified distance matrix (U-matrix) metric is employed in the classification stage [3]. This method has been demonstrated to enhance the ATR performance remarkably compared with that obtained by major neural network or SVM-based approaches because it assesses not only differences in output from training and test inputs, but also the potential barrier generated by the U-matrix metric.

It should be noted that this method only deals with single polarimetric SAR data. As suggested in various studies, full polarimetric SAR data have great potential for improving ATR performance [4]. There are many studies on full polarimetric SAR analysis that focus on structure recognition such as the ground surface, paddy fields, forests, or artificial buildings. For this background, this paper extends the conventional SOM based ATR method [3] to be suitable for full polarimetric data where the dimension of input vector is simply trebled. Furthermore, the conventional method suffers from inaccuracy for classification, where an unknown input image has different azimuth angle from the training image, namely, in target rotating situation. There is the extended method to deal with this problem [5], where multi-training data with different azimuth angle are preliminary learned in SOM. However, it requires more training data and larger SOM neurons. To overcome this difficulty, this paper also introduces the rotation angle compensation method and employs the circular polarization basis conversion. The literature [6] reports that the power ratio of circular polarization component is invariant for target rotation regardless of target structure, and it is suitable for dealing with the above problem. The experimental data, obtained in assuming the 1/100-scale model of an X-band radar, demonstrate that the proposed method enhances recognition accuracy by using circular polarization basis, where the target aircraft has a different azimuth angle.

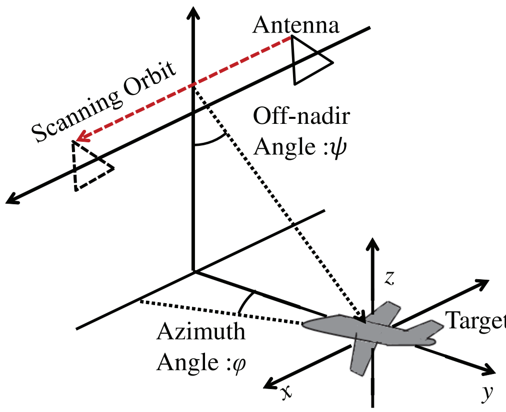

Fig. 1. System model.

2. SYSTEM MODEL

Figure 1 shows the geometry of the observation model. It assumes a mono-static radar, where a set of transmitting and receiving antennas is scanned along the straight line as $y = y_0$, $z = z_0$. The target is located on the plane at $z = 0$, the off-nadir angle is ψ. The target rotates along the z axis, and its rotation angle (called azimuth angle) is denoted by ϕ. The two linear polarizations are assumed as the vertical (denoted by V) and horizontal (denoted by H) directions in the transmitting and receiving antennas. Then, the full combination of polarimetric data as VV, VH, HV, and HH are obtained (e.g., VH denotes vertical polarization in transmitting and horizontal polarization in receiving). Here, it assumes the reciprocity as $\mathrm{HV} = \mathrm{VH}$. The polarimetric SAR complex image, focused on the $z = 0$ plane, is defined as $S_{ij}(x, y)$, where the subscripts i and j denote H or V.

3. PROPOSED SOM BASED ATR METHOD

We have already proposed the efficient ATR method, which is based on the supervised SOM and U-matrix metric [3]. While it has been reported that this method significantly enhanced the recognition accuracy by exploiting the feature of U-matrix field [3], this method suffers from the degradation of recognition performance, where an unknown target image has a different azimuth angle of the training data. To overcome the above problem, the proposed method introduces the rotation angle compensation method and employs the circular polarization basis conversion, when the training data with one azimuth angle is only input to the SOM.

3.1. Target area extraction

First, to reduce the noise, this paper synthesizes each polarimetric SAR image weighted by the PSNR (Peak SNR) in each polarimetric SAR image as

$$P_{\mathrm{full}}(x, y) = \hat{\sigma}_{\mathrm{HH}}\langle|S_{\mathrm{HH}}|^2\rangle + 2\hat{\sigma}_{\mathrm{HV}}\langle|S_{\mathrm{HV}}|^2\rangle + \hat{\sigma}_{\mathrm{VV}}\langle|S_{\mathrm{VV}}|^2\rangle, \quad (1)$$

where $\hat{\sigma}_{ij}(i, j = \mathrm{H}, \mathrm{V})$ is the normalized weight coefficient defined as

$$\hat{\sigma}_{ij} = \frac{\sigma_{ij}}{\sigma_{\mathrm{HH}} + 2\sigma_{\mathrm{HV}} + \sigma_{\mathrm{VV}}}, \quad (2)$$

$$\sigma_{ij} = \frac{\max_{x,y\in\Omega}\langle|S_{ij}(x, y)|^2\rangle}{\mathrm{mean}_{x,y\in\Omega_{\mathrm{N}}}\langle|S_{ij}(x, y)|^2\rangle}. \quad (3)$$

Here, Ω denotes the entire area of the image, Ω_{N} denotes the focused area by received signals not including target echoes and $\langle * \rangle$ represents spatial average. Then, the target area denoted as Ω_{tar} is determined as;

$$\Omega_{\mathrm{tar}} = \{(x, y) \in \Omega \mid P_{\mathrm{full}}(x, y) \geq P_{\mathrm{th}}\}, \quad (4)$$

where P_{th} denotes the threshold, preliminarily determined.

3.2. Azimuth angle compensation

This subsection explains the extension of the conventional ATR method [3] to full polarimetric SAR images to enhance the robustness against the target azimuth rotation. First, as a preprocessing, this paper introduces the azimuth angle compensation method. The azimuth direction ϕ of unknown image is estimated as

$$\hat{\phi} = \underset{-\frac{\pi}{2}\leq\phi\leq\frac{\pi}{2}}{\arg\max} \frac{\sum_{x,y} P^{\mathrm{bi}}(x, y)P^{\mathrm{bi}}_{\mathrm{ref}}(x, y, \phi)}{\sqrt{\sum_{x,y} P^{\mathrm{bi}}(x, y)^2}\sqrt{\sum_{x,y} P^{\mathrm{bi}}_{\mathrm{ref}}(x, y, \phi)^2}}, \quad (5)$$

where $P^{\mathrm{bi}}(x, y)$ is the binarized image of feature value $P_{\mathrm{full}}(x, y)$ defined as;

$$P^{\mathrm{bi}}(x, y) = \begin{cases} 1 & (P_{\mathrm{full}}(x, y) \geq \hat{P}_{\mathrm{th}}), \\ 0 & (\mathrm{Otherwise}). \end{cases} \quad (6)$$

where the threshold $\hat{P}_{\mathrm{th}}$ is automatically determined by Otsu's discriminant analysis. $P^{\mathrm{bi}}_{\mathrm{ref}}(x, y, \phi)$ denotes the image rotating the reference image $P^{\mathrm{bi}}_{\mathrm{ref}}(x, y)$ with ϕ around the target center point.

3.3. Feature value extension for full polarimetric data

Next, the feature value of training and unknown images is extended to full polarimetric data. Although the full polarimetric data, in general, is observed from the linear polarization (LP) basis, it has been reported that the power ratio of the LP components varies due to the target rotation [6]. This variations become critical for ATR performance in the method [3],

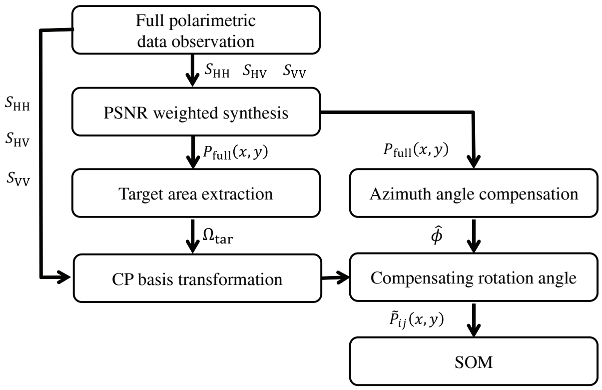

Fig. 2. Flowchart of the proposed method.

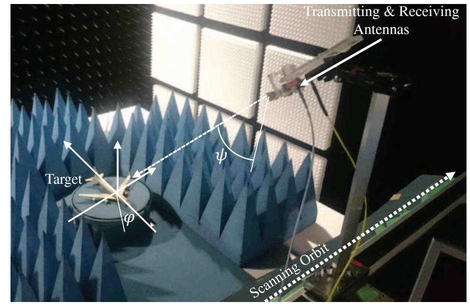

Fig. 3. Experimental setup.

because it compares spatial distribution of the power for each polarization SAR image. On the contrary, it has been found that the power ratio of circular polarization (CP) component is invariant for target rotation in [6]. Thus, this paper introduces the CP basis to maintain the ATR performance for target rotation. The scattering matrix of the LP basis is transformed to that of CP basis as;

$$\boldsymbol{S}_{\mathrm{CP}}(x,y) = \begin{bmatrix} S_{\mathrm{LL}}(x,y) & S_{\mathrm{LR}}(x,y) \\ S_{\mathrm{RL}}(x,y) & S_{\mathrm{RR}}(x,y) \end{bmatrix}$$
$$= \frac{1}{2}\begin{bmatrix} 1 & \mathrm{j} \\ \mathrm{j} & 1 \end{bmatrix}\begin{bmatrix} S_{\mathrm{HH}}(x,y) & S_{\mathrm{HV}}(x,y) \\ S_{\mathrm{VH}}(x,y) & S_{\mathrm{VV}}(x,y) \end{bmatrix}\begin{bmatrix} 1 & \mathrm{j} \\ \mathrm{j} & 1 \end{bmatrix} \quad (7)$$

where the subscripts L and R denote the left-handed and right-handed circular polarizations, respectively. Then, the proposed method introduces the feature values $\boldsymbol{Z}_{\mathrm{CP}}$ for training and unknown data as

$$\boldsymbol{Z}_{\mathrm{CP}} = \frac{[\boldsymbol{z}_{\mathrm{LL}}, 2\boldsymbol{z}_{\mathrm{LR}}, \boldsymbol{z}_{\mathrm{RR}}]}{\max_{x,y\in\Omega}(\boldsymbol{z}_{\mathrm{LL}} + 2\boldsymbol{z}_{\mathrm{LR}} + \boldsymbol{z}_{\mathrm{RR}})}. \quad (8)$$

Ω is the entire area of the SAR image. Here, the SAR image vector $\boldsymbol{z}_{ij} (i = \mathrm{L} \text{ or } \mathrm{R}, j = \mathrm{L} \text{ or } \mathrm{R})$ is determined as;

$$\boldsymbol{z}_{ij} = \Big[\tilde{P}_{ij}(x_1,y_1),\cdots,\tilde{P}_{ij}(x_1,y_{N_{\mathrm{y}}}), \cdots,\tilde{P}_{ij}(x_{N_{\mathrm{x}}},y_1)\cdots,\tilde{P}_{ij}(x_{N_{\mathrm{x}}},y_{N_{\mathrm{y}}})\Big] \quad (9)$$

where N_{x} and N_{y} denote the total number of pixels along the x and y axes. Here, $\tilde{P}_{ij}(x,y)$ is defined as;

$$\tilde{P}_{ij}(x,y) = \begin{cases} \langle|S_{ij}(x,y)|^2\rangle & ((x,y)\in\Omega_{\mathrm{tar}}), \\ 0 & (\mathrm{Otherwise}). \end{cases} \quad (10)$$

Ω_{tar} is determined as in Eq. (4). Figure 2 shows the flowchart of the proposed method.

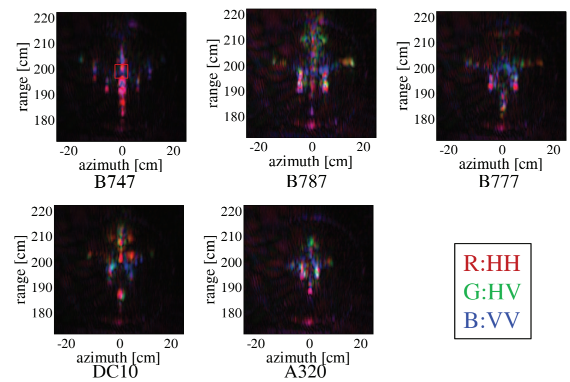

Fig. 4. RGB expression for SAR images on LP basis for each airplane at $\phi = 0°$.

4. PERFORMANCE EVALUATION BY EXPERIMENT

This section describes the ATR performance through experimental investigation. It assumes about 1/100-scale model of a typical X-band radar system, except for the center frequency. Figure 3 shows the experimental setup. Here, the off-nadir angle ψ is 65°, height of the antenna is 1.14m, frequency is swept from 26GHz to 40GHz, and synthetic aperture length is 1.6 m. The azimuth direction of targets is defined as ϕ in Fig. 1. The five types of civilian aircrafts, as B747, B787, B777, DC10, and A320, are assumed for the target classification issue.

For the relevance of the proposed method, the power ratio variation of each polarization basis is assessed as follows. Figures 4 shows the RGB synthesized SAR images on LP basis at $\phi = 0°$. In addition, Fig. 5 shows the quantitative validation of the power ratio for each polarization on LP basis and CP basis. Here, the power ratio is the averaged power ratio for each polarization in the red marker region at $\phi = 0°, 30°$, re-

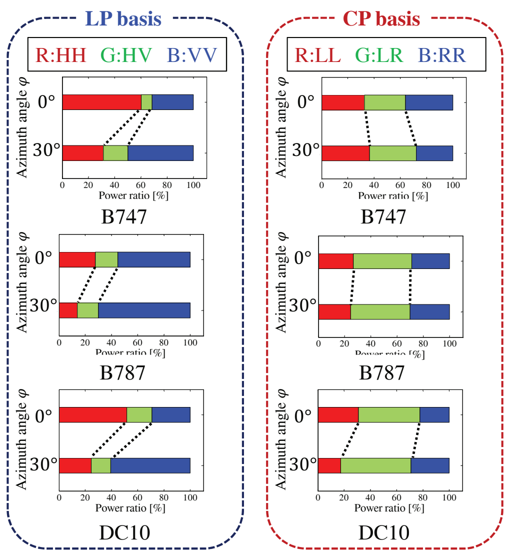

Fig. 5. Power ratios of LP and CP basis in red marked area.

spectively. As shown these figures, it is found that the power of each polarization on LP basis is changed in azimuth direction variation. On the contrary, the power ratio on CP basis is almost invariant for target rotation because the polarization components on CP basis are invariant for azimuth direction variation.

Next, the target classification accuracies of the proposed method and other possible combinations are investigated as follows. The neuron size of the assumed SOM is set to 31×31 and the total number of training trials is set to $T_{\rm som} = 30$. The training data for each aircraft with $\phi = 0^\circ$ are used for generating the SOM, namely, the learning process. The unknown SAR images are investigated, where the rotating azimuth angle ϕ is varied for $-30^\circ \leq \phi \leq 30^\circ$ with the 2° interval. In the angle compensating process, the reference image $P_{\rm ref}^{\rm bi}(x, y, 0)$ is set to that obtained at B747 with $\phi = 0^\circ$. Table 1 shows the probabilities of correct classification for each method at the averaged PSNR = 32 dB. Here, the PSNR is averaged for all polarization and all targets. As shown in these tables, the full polarimetric exploitation denoted as LP or CP basis is effective for improving the ATR performance in terms of correct classification probability. Especially, the average probabilities of correct classification by the proposed method achieves the highest one in those of all single polarization data or the LP based full polarimetric exploitation. This is because the feature value consisting of CP basis component is basically invariant for target rotation, and contributes the correct target classification by suppressing the undesirable changes of the feature values due to the target rotation.

Table 1. Comparison of probability for correct classification at average PSNR = 32 dB.

		B747	B787	B777	DC10	A320	AVE
Single Pol.	HH	90 %	52%	97%	81%	42%	72%
	VV	90 %	65%	58%	97%	32%	68%
	HV	87%	39%	94%	55%	68%	68%
Full Pol.	LP	77%	42%	100%	68%	100%	77%
	CP	100%	42%	100%	97%	94%	87%

5. CONCLUSION

This paper extended the SOM based former method so as to exploit full polarimetric SAR images. Especially, the former SOM based ATR method is appropriately extended to full polarimetric data to be suitable for target rotating situation, where the target rotating angle estimation and CP basis conversion are newly introduced. The experimental validations, assuming the 1/100-scale X-band SAR model, demonstrated that our proposed method achieved the highest accuracy in terms of target area extraction and correct target classification under angular varying situations.

6. REFERENCES

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