Time Series SAR Polarimetric Analysis of Rice Crop based on Four-Component Scattering Decomposition

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1. Introduction

Terrain and land use classification is one of the most important applications of polarimetric synthetic aperture radar [1]. Various methods have been proposed to classify terrain based on polarimetric statistical characteristics. A four-component scattering decomposition [2] scheme based on the coherency matrix [3] has been proposed to supplement the common three-component decomposition by Freeman and Durden[4] by adding a helix components that represent scattering contribution from complex urban environment. This paper applies the four-component decomposition to analyze the polarimetric response of rice crop from time series of polarimetric SAR data acquired from RADARSAT-2. To trace the growth stage, change detection was performed over the four components, with surface scattering, volume scattering, double bounce, and helix scattering as feature vector, using CFAR detector.

2. Data Set and Test Site

Quad-pol images of Radarsat-2 were acquired in March 15, 2009; April 8, 2009; May 26, 2009; June 19, 2009; August 6, 2009 and August 30, 2009 with a 24-day repeated cycle. The RADARSAT-2 images have a nominal spatial resolution of 5.4 m in slant range by 7.9 m in azimuth, with a pixel size of 4.7 m × 4.9 m. The swath width of the image is about 25 km. The incidence angle is from 34.62∘ at near range to 36∘ at far range. The images sets and acquisition mode is listed in Table 1. Dongshih Farm, a reclaimed coastal land in western Taiwan covering various tree plantations, rice field, ponds, was selected as the test site.

3. Method

In this study, the following methods are used for rice growth detection. Make radiometric correction by SLC image to create the polarimetric coherency matrix averaged by 5x5 windows. After orientation compensation, the new coherency matrix can be applied to surface scattering, double bounce scattering, volume scattering and helix. This paper use four-component decomposition images to create growth detection by CFAR.

According to [2], it is necessary to evaluate the second-order statistics of scattering matrix in order to derive polarimetric scattering characteristics in a quad-pol image. The coherency matrix is expressed as

$$\left\langle [T] \right\rangle^{HV} = \begin{bmatrix} \frac{1}{2}\left\langle \left| S_{HH}+S_{VV} \right| \right\rangle^2 & \frac{1}{2}\left\langle (S_{HH}+S_{VV})(S_{HH}-S_{VV})^* \right\rangle & \left\langle (S_{HH}+S_{VV})S_{HV}^* \right\rangle \\ \frac{1}{2}\left\langle (S_{HH}-S_{VV})(S_{HH}+S_{VV})^* \right\rangle & \frac{1}{2}\left\langle \left| S_{HH}-S_{VV} \right|^2 \right\rangle & \left\langle (S_{HH}-S_{VV})S_{HV}^* \right\rangle \\ \left\langle S_{HV}(S_{HH}+S_{VV})^* \right\rangle & \left\langle S_{HV}(S_{HH}-S_{VV})^* \right\rangle & \left\langle 2\left| S_{HV} \right| \right\rangle^2 \end{bmatrix} \quad (1)$$

From [2], the coherency matrix (1) can be expanded as

$$\langle[T]\rangle^{HV} = f_s\langle[T]\rangle^{hv}_{surface} + f_d\langle[T]\rangle^{hv}_{double} + f_v\langle[T]\rangle^{hv}_{volume} + f_c\langle[T]\rangle^{hv}_{helix}$$
$$= f_s\begin{bmatrix} 1 & \beta^* & 0 \\ \beta & |\beta|^2 & 0 \\ 0 & 0 & 0 \end{bmatrix} + f_d\begin{bmatrix} |\alpha|^2 & \alpha & 0 \\ \alpha^* & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} + \frac{f_v}{4}\begin{bmatrix} 2 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} + \frac{f_c}{4}\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & \pm j \\ 0 & \mp j & 1 \end{bmatrix} \quad (2)$$

where f_s, f_d, f_v, and f_c are the expansion coefficients to be determined from polarimetric data. The window size to estimate the coherency matrix was 5 x 5 in this paper.

According to the decomposition algorithm, the total scattered power, $P_t = P_s + P_d + P_v + P_c = \left\langle |S_{HH}|^2 + 2|S_{HV}|^2 + |S_{VV}|^2 \right\rangle$ can be decomposed into four scattering components P_s, P_d, P_v, and P_c corresponding to surface, double bounce, volume, and helix scattering, respectively, and are determined by the expansion coefficient given in (2):

$$\begin{aligned} P_s &= f_s(1 + |\beta|^2), \\ P_d &= f_d(1 + |\alpha|^2), \\ P_v &= f_v, \\ P_c &= f_c \end{aligned} \quad (3)$$

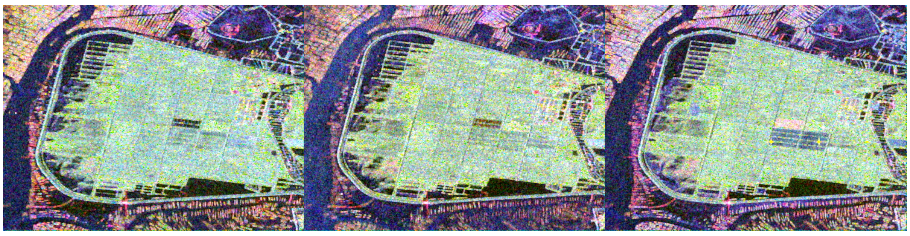
Before decomposition, orientation compensation is necessary to correct some double bounce responses which change the response characteristic by different azimuthal angle. The most significantly target is like man-made building which is not aligned in the along-track direction. After orientation compensation, only azimuthal rotation angle less than ±22.5° can be corrected successfully.[5-6].

4. Results and Discussion

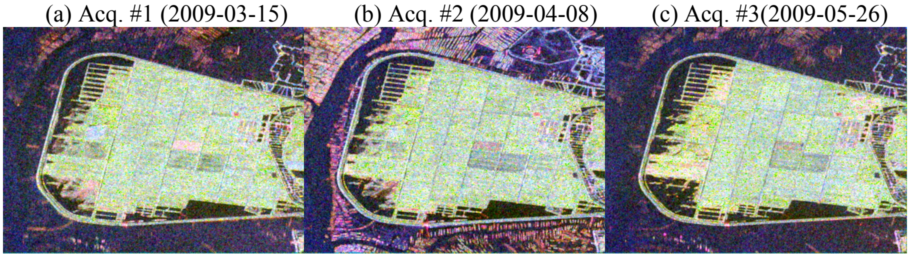
Fig.1 shows a color composite of four-component decomposition from Radarsat-2 images over Dongshih farm, Taiwan. The rice field was roughly around the scene centre, with enlarged portion indicated by the rectangular box, as shown in Fig. 2. Ground truth was conducted in 2009-5-26. Corner reflector (CR) and active radar calibrator (ARC) were also deployed to provide geometric and radiometric references. The responses were indicated in Fig.2(c). It is clearly observed that in transplantation stage (Fig.2 (a)), backscattering returns was very weak, acted as fairly flat surface. In seeding developing stage, the dominate scatterer remained flat surface but certain degree of volume and double bounce signals appeared. As rice kept growing into tillering stage, shown in Fig.2(c),(d), polarimetric response was dominated by double bounce scatterings probably due to ploughing cultivating. At the reproductive and ripening stages, mixture responses were revealed, shown in Fig.2. The ground truth photos in 2009-05-26 show in Fig. 3. It shows that the plant height was about 25 cm at this stage. Fig. 4 (a) to (c) displays the backscattering returns of linear basis, Pauli basis, and Y4R basis. The scattering power varied with rice growth stage, from bare surface, plant cover, and back to bare surface, all physically interprets the ground cover changes. It is of interest to perform the change detection between data sets of 2009.04.08 and 2009.05.26 in which clear land cover changed was observed. Two CFAR rate (90%) and (99%) were tested. It is clear from Fig. 5 that among the linear, Pauli, Three component, original four component(Y40) and orientated four component(Y4R) basis, the oriented four component decomposition(Y4R) offers the correct and best detection performance of CFAR. Three component and original four component(Y40) provide similar CFAR result but Pv.

5. Summary

A four-component scattering decomposition (Y4R) based on the coherency matrix is applied to analyze the polarimetric response of rice crop growth. A multi-temporal Radarsat-2 Quad-Pol SAR dataset from March to August, 2009 over western Taiwan was collected. Compared to other decomposition schemes such as lexicographic covariance matrix approach and Pauli-based covariance matrix, the four-component decomposition offers excellent performance to identify the crop growth stages in terms of polarimetric scattering responses from transplanting to harvesting. Results indicate that Y4R provides excellent features for change detection based on constant false alarm rate (CFAR) scheme.

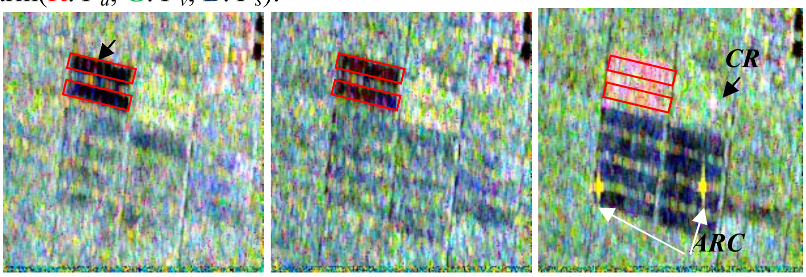


(a) Acq. #1 (2009-03-15) (b) Acq. #2 (2009-04-08) (c) Acq. #3(2009-05-26)

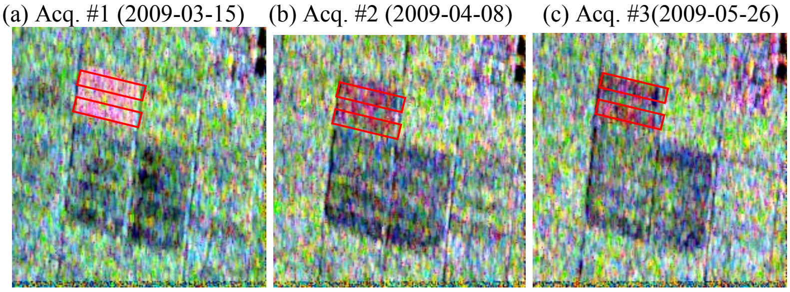


(d) Acq. #4 (2009-06-19) (e) Acq. #5 (2009-08-06) (f) Acq. #6 (2009-08-30)

Fig.1 Time series of Quad-Pol Radarsat-2 dataset after four-component decomposition over Dong-shih farm(R: P_d, G: P_v, B: P_s).



(a) Acq. #1 (2009-03-15) (b) Acq. #2 (2009-04-08) (c) Acq. #3(2009-05-26)



(d) Acq. #4 (2009-06-19) (e) Acq. #5 (2009-08-06) (f) Acq. #6 (2009-08-30)

Figure.2 Enlarged portion of rice field in Fig.1

Fig. 3 Photos of rice field taken in 2009-05-26

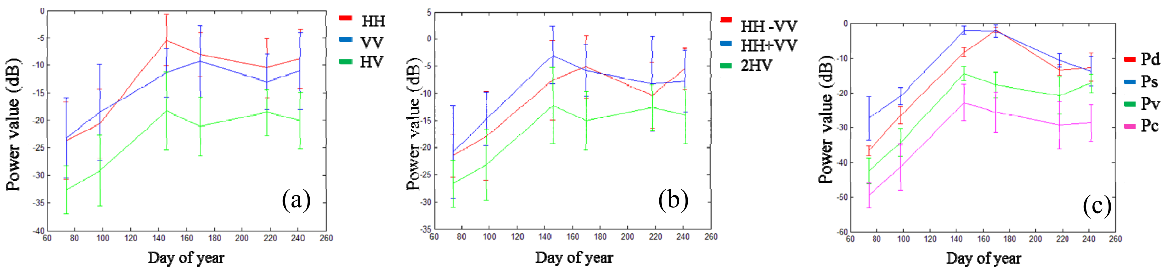


Fig.4 Time series of backscattering returns of (a) Linear basis (b) Pauli basis and (c) Y4R on rice field.

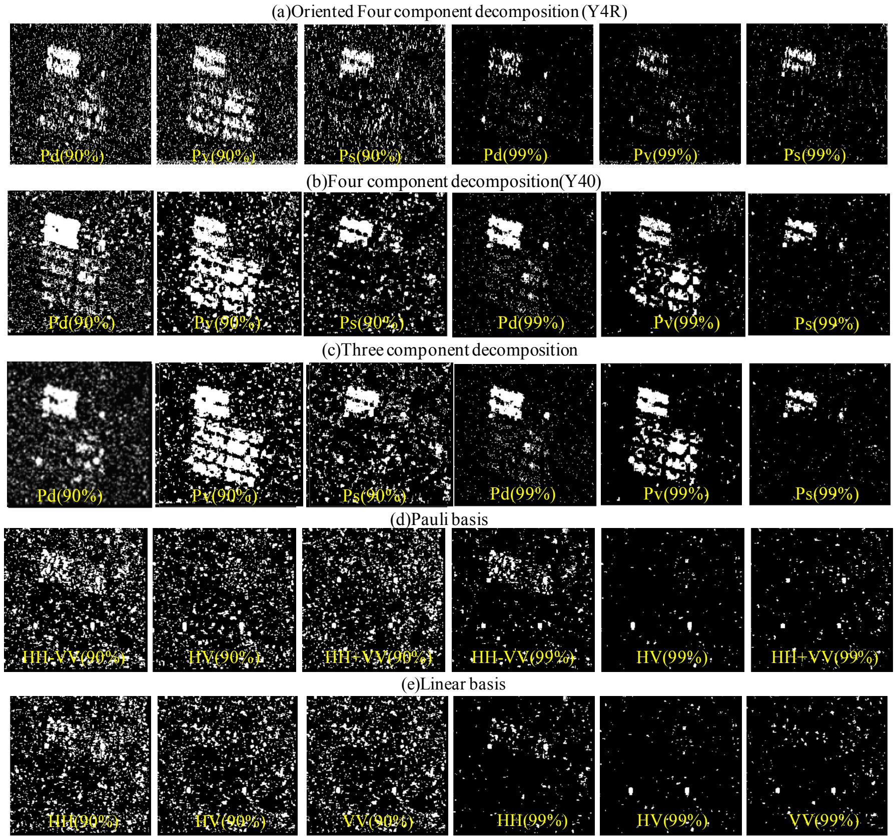


Fig.5 Change detection based on (a)Y4R, (b)Y40, (c)three component, (d) Pauli basis and (e)linear basis with CFAR 90% and 99%, between data taken in 2009.04.08 and 2009.05.26.

Table 1. RADARSAT-2 Fine Quad-Pol Mode data set

Acq.#	Data	Orbit	Beam
1	2009-03-15	18-76A	FQ15
2	2009-04-08	19-119A	FQ15
3	2009-05-26	21-119A	FQ15
4	2009-06-19	22-119A	FQ15
5	2009-08-06	24-119A	FQ15
6	2009-08-30	25-119A	FQ15

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