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Polarimetric analysis of long term paddy rice observation using ground-based SAR (GB-SAR) system

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Abstract

The synthetic aperture radar (SAR) has been utilized for generating image of the earth surface by synthesizing the antenna along the azimuth flight pass as signal processing. This technique recently provides us abundant information by using the polarimetric data of linear polarized (LP) antennas. In recently, Josaphat Microwave Remote Sensing Laboratory (JMRSL) developed ground-based SAR (GB-SAR) for precise monitoring of several targets and SAR experiment inside an anechoic chamber. In this paper, we introduce the paddy rice observation by using the developed GB-SAR system and that of polarimetric analysis. To observe the paddy rice using SAR is very promising since SAR observation doesn't face the problem of whether condition. We conducted the paddy rice observation experiment inside an JMRSL anechoic chamber. More accurate results can be corrected than SAR onboard satellite by testing inside the anechoic chamber and using the GB-SAR with wideband frequency. The GB-SAR is comprised of vector network analyzer (VNA), quad ridged horn antennas, and position controller. The SAR image was reconstructed by back projection algorithm with inverse SAR (ISAR) experimental method for high resolution image. We have observed the paddy rice from beginning of the June until end of September to analysis according to the growth stages. As a polarimetric analysis, we applied model based decomposition technique in linear polarization (LP) basis proposed by Yamaguchi to each SAR images. The result from series of measurements show strong dependency on the off-nadir angle and unignorable high helix scattering effect.

Keywords
SAR; GB-SAR; Polarimetry; Paddy rice.

1. Introduction

The synthetic aperture radar (SAR) is imaging radar which can obtain interest target by collecting scattering signals along the azimuth line. Since this technique uses

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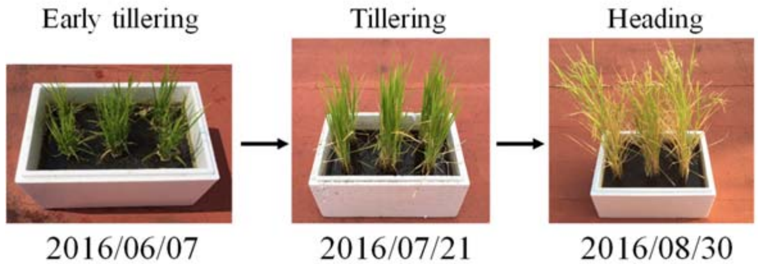

Fig. 1. Photograph of paddy rice according to the growth stages.

Table 1. List of paddy rice height according to the observation date.

Test date	Jun.7	Jun.22	Jul.6	Jul.21	Aug.3	Aug.22 (ear emergence)	Aug.30	Sep.14
Height [cm]	19	27	34	42	49	52	52	45

microwave as transmitting signal, it can generate the images without consideration of weather condition and observation time.

The polarimetric information obtained by polarimetric synthetic aperture radar (polSAR) becomes important factor for observation of paddy field. Until now, several papers have investigated the relationship between microwave scattering and growth stage of paddy rice using polSAR data of SAR onboard satellite and aircraft and ground-based SAR (GB-SAR) (Hayashi and Sato, 2009), (Li et al., 2012). The paddy rice observation by using especially GB-SAR can select variety of frequencies and use wide frequency range, compared to SAR onboard satellite and aircraft (Hayashi and Sato, 2009). However, few papers have studied long term paddy rice observation of GB-SAR until now.

In this paper, we conduct polarimetric analysis of long term paddy rice observation (beginning of June until end of September) according to the seasonal growth stage by using developed GB-SAR system inside of an anechoic chamber. As the polarimetric analysis, we applied four component decomposition technique which decomposes the scattering power to several scattering mechanisms such as surface, double-bounce, volume, and helix scattering proposed by Yamaguchi et al. (Yamaguchi et al., 2005)

2. Four component polarimetric SAR image decomposition

Depends on the target geometry, scattering mechanism which is characterized by the scattering matrix of polarimetric SAR data is determined. Scattering matrix in linear polarization basis has four complex coefficients: HH, HV, VH, and VV of linear polarization where each coefficient of amplitude and phase is determined by scattering mechanism of interest target. The polarimetric SAR data has advantage of characterizing scattering mechanism of specific target by adopting decomposition technique. Four component polarimetric SAR image decomposition is one of the promising decomposition techniques which is proposed by Yamaguchi *et al*. This technique decomposes into four scattering mechanism categories of surface, double-bounce, volume, and helix scattering by using the coherency or covariance matrix. Here for example using well known covariance matrix of each scattering mechanism, the measured covariance matrix $\langle [C] \rangle$ ($\langle \cdot \rangle$ denotes the ensemble average) in HV-basis (linear polarization basis) can be decomposed as

$$\left\langle [C] \right\rangle^{\mathrm{HV}} = f_s \left\langle [C] \right\rangle^{\mathrm{HV}}_{surface} + f_d \left\langle [C] \right\rangle^{\mathrm{HV}}_{double} + f_v \left\langle [C] \right\rangle^{\mathrm{HV}}_{volume} + f_c \left\langle [C] \right\rangle^{\mathrm{HV}}_{helix} \quad (1)$$

where f_s, f_d, f_v, and f_c are defined as constant number of surface, double-bounce, volume, and helix scattering respectively. The four component decomposition process can be

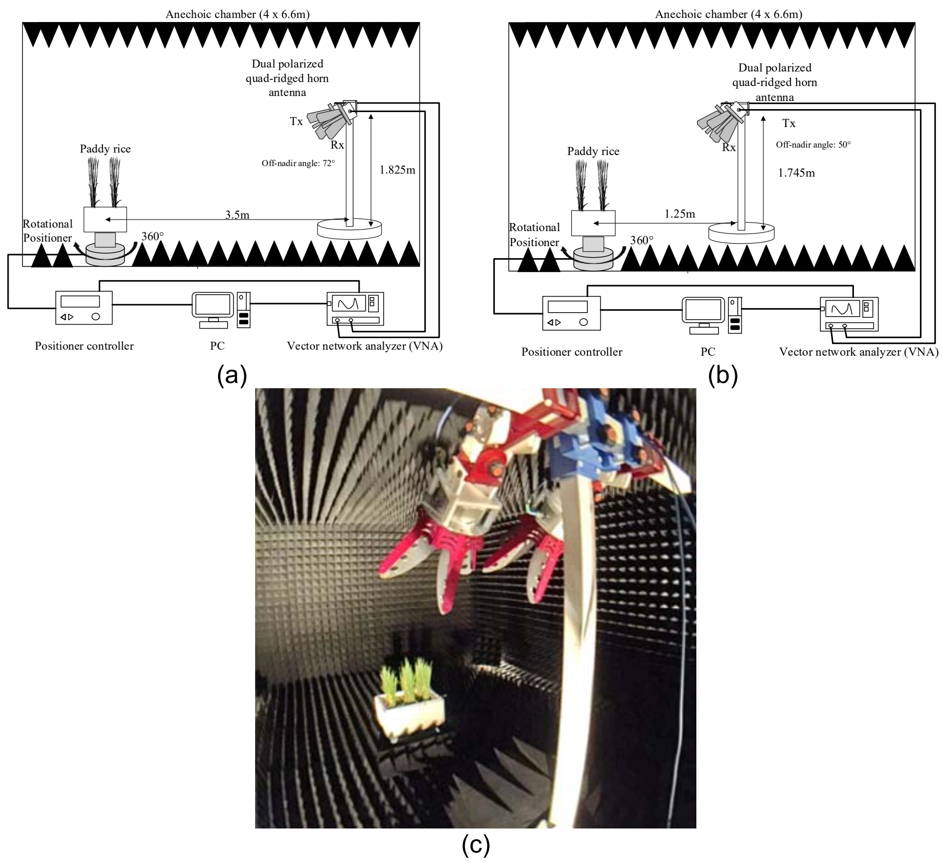

Fig. 2. Constructed GB-SAR system network inside the anechoic chamber. (a) Geometry with 72°off-nadir angle (b) Geometry with 50°off-nadir angle (c) Photograph from actual experiment with 50°off-nadir angle.

done after deriving four constant number of each power of scattering mechanism. More specific decomposition process can be referred from (Yamaguchi et al., 2005).

3. Experiment

To analyze the paddy rice using polarimetric decomposition technique, 8 times of paddy rice observation data were collected from June 7th until September 14th of 2016. These observations were conducted by using paddy rice as a target and developed GB-SAR system. To analyze the incidence angle dependency, the measurements were carried out with two specific off-nadir angles: 72° and 50°. Note that the primary measurement of June 7th miss the 50° off-nadir angle measurement data because of corrupt data.

3.1. Paddy rice

We had cultivated the paddy rice from early tillering stage until harvesting in outside of our laboratory, as shown in Fig. 1. By cultivating our-self, every parameter related to paddy rice such as water and soil amount can be controlled easily. In addition, we can bring it into the anechoic chamber, and thus observation becomes possible with controlled environment. 6 paddy rice which are planted inside of the polystyrene box with 13.5cm height of soil and 14.5cm of water are used to suppress the undesired backscattering from the box. The paddy rice height according to the observation date are listed in Table 1. Ear emergence started from Aug. 22.

3.2. Polarimetric GB-SAR system

The developed GB-SAR system is constructed by a vector network analyzer (VNA), a positioner controller, a rotational positioner, a PC, and quad-ridged horn antennas, as

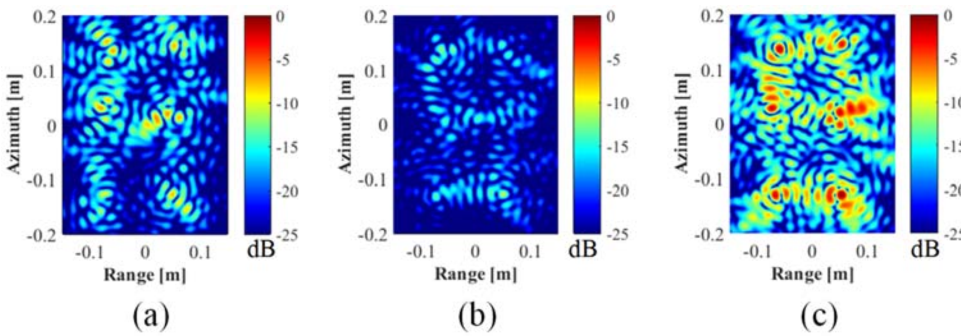

Fig. 3. Generated SAR images with 50° off-nadir angle obtained in Sep.14. (a) HH (b) HV (c) VV

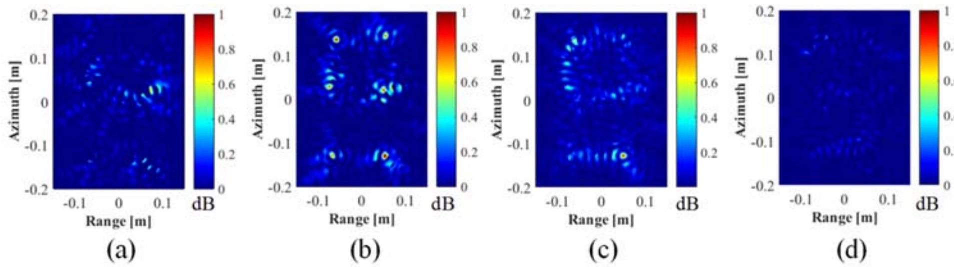

Fig. 4. Decomposed SAR images with 50° off-nadir angle obtained in Sep.14. (a) Surface scattering (b) Double bounce scattering (c) Volume scattering (d) Helix scattering

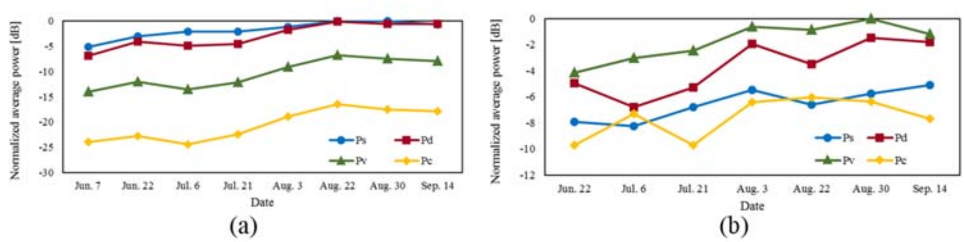

Fig. 5. The normalized average power. (a) off-nadir 72°. (b) off-nadir 50°.

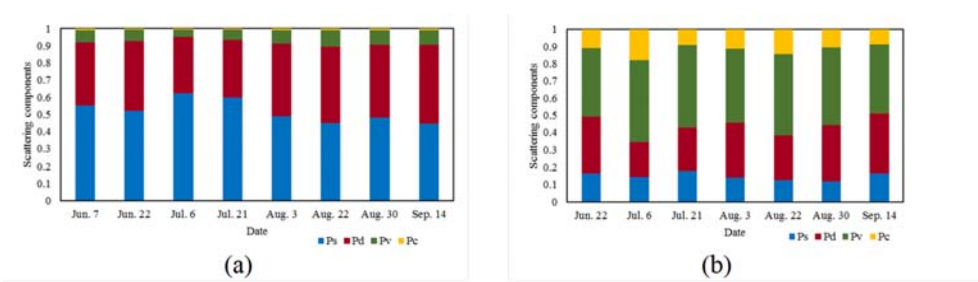

Fig. 6. Relative scattering components of Ps, Pd, Pv, and Pc. (a) off-nadir 72°. (b) off-nadir 50°.

shown in Fig. 2. This setup achieves a stepped frequency continuous radar (SFCW) configuration and wide-band observation since the antennas can be used in frequency range from 700 MHz until 10 GHz. The inverse SAR (ISAR) method, where target rotates in static place while SAR collecting the receiving data, was adopted to this observation. Because the target is in the antenna footprint all time during the measurement, this method is considered as spotlight mode and can obtain high resolution images compared to stripmap GB-SAR measurement.

4. Experimental results and discussion

The generated SAR images with 50° off-nadir angle which is obtained in Sep.14 are shown in Fig. 3 as representative of many images. These images are normalized to 0 dB as choosing a maximum value among three images. HH, HV, and VV polarization images are placed in Fig. 3 respectively. Fig. 3 shows the clear dots which represent the planted place of paddy rice. In addition, this figure shows highest scattering from VV-polarization because paddy rice stands as vertical shape.

Fig. 4 shows the images which is decomposed to each power component of Ps (surface scattering), Pd (double-bounce scattering), Pv (volume scattering), and Pc (helix scattering) from SAR images of Fig. 3. Furthermore, we calculated average power values from each decomposed power image and performed normalization to the maximum power in whole values, shown in Fig. 5, and scattering component rate is shown in Fig. 6. From these figures, the obvious difference between two off-nadir angles are observed. The measurements with 72° off-nadir angle indicate that the surface and double-bounce scattering are dominant among the 4 scattering components while the measurements with 50° show the highest volume scatterings and unignorable high helix scattering (Figure 6). This result indicates that the helix scattering is also one of the important factor for paddy rice monitoring, although many literatures have discussed paddy rice monitoring without considering of Pc scattering until now.

Although the seasonal results show strong dependency on the off-nadir angle, characterizing the paddy rice according to the observation time is not enough. Therefore, further analysis such as H/alpha decomposition is planted to conduct.

5. Conclusion

Seasonal paddy rice observations have been conducted by using pol-GB-SAR with two specific off-nadir angles. The 6 paddy rice which are planted inside of the polystyrene box are used in the measurement. To perform the polarimetric analysis, four components polarimetric SAR decomposition technique is processed in each SAR images. The seasonal results show high dependency on the off-nadir angle in the paddy rice observation and unignorable helix scattering effect for observing paddy fields. However, the decomposition analysis is not enough to characterize the paddy rice according to the observation date. Therefore, more analysis will be performed as a next step of this study.

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