Ground-Based Polarimetric SAR Systems for Environment Studies

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1. Introduction

Polarimetric SAR interferometry is a compound technique that has shown an ability to extract geophysical parameters from SAR images and its usefulness in terrain classification and surface change detection. SAR is a well-known technique for airborne or spaceborne remote sensing. It can usefully be exploited in a ground-based radar imaging system. A ground-based SAR system has recently been proposed as a large structure monitoring tool for environment study and deformation detection. Precise monitoring of the deformation of ground surface and the surface of constructions is very important in many engineering applications. For instance, monitoring of volcano activities by observing the surface movement will be advantageous for disaster prevention. For these applications, ground-based SAR has wide range of applications and advantages due to the performances of broadband electromagnetic wave. Moreover, it can be applied to detect the structure of subsurface and surface movement even under cloudy and dusty conditions where other techniques, such as laser distance meter, cannot be used. By using radar polarimetry, a ground-based SAR system can be also used for monitoring vegetation changes with seasonal variation. We developed a ground-based polarimetric SAR system for environment studies. This system is based on a vector network analyzer, polarized antennas and a scanning control unit. In this paper, we will describe the ground-based polarimetric SAR system and present some experiment results of monitoring trees with seasonal variation.

2. Ground-based Polarimetric SAR System

A vector network analyzer (Agilent HP8720ES) based radar system consisting of two dual polarized diagonal horn antennas (ETS-EMCO model 3164-03), antenna position unit was developed. Synthetic aperture is realized by scanning the antenna system on a horizontal rail and moving along a vertical bar. This system may works at frequency from 400 MHz up to 6 GHz, and scanning aperture of antennas is 20 m in horizontal and 1.5 m in vertical dimensions. The working frequency range will be from 50 MHz up to 20 GHz while the double-ridged waveguide horn antennas (Antenna Giken Corp.) are employed.

We carried out some experiments with a few of standard reflectors to demonstrate the polarimetric performance of this ground-based polarimetric

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SAR system. First, a test with a calibrator of a metallic sphere has been performed. We can find that the measured backscattering of co-polarization in Fig. 1(b) is consistent with the theory in Fig. 1(a). Then we used a vertical dihedral, a 45-degree dihedral, a vertical wire and a –45-degree wire as the radar targets. The scattering matrix at frequency 2 GHz for each reflector is calculated from fully polarimetric measured data as below.

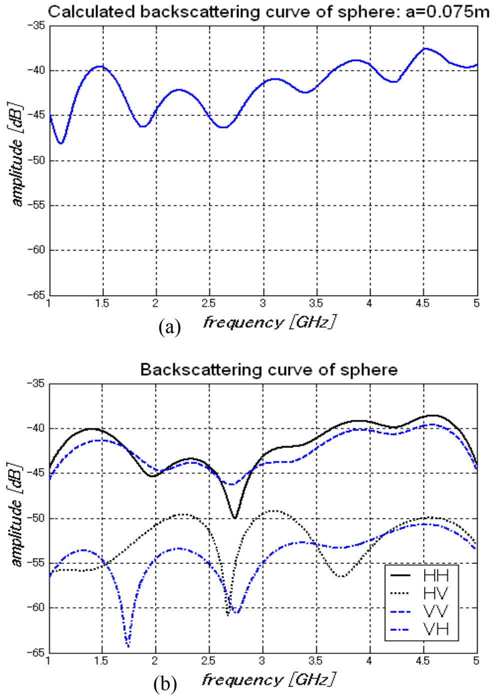

Fig. 1 Backscattering from metallic sphere:
(a) calculated, (b) measured

Vertical dihedral:

$$S_{m1}=\begin{bmatrix}0.9813e^{-j113.7^\circ} & 0.0365e^{j129.4^\circ}\\ 0.0365e^{j129.4^\circ} & 1\end{bmatrix} \tag{1}$$

45-degree dihedral:

$$S_{m2}=\begin{bmatrix}0.2977e^{j120.4^\circ} & 1\\ 1 & 0.2891e^{j112.3^\circ}\end{bmatrix} \tag{2}$$

Vertical wire:

$$S_{m3}=\begin{bmatrix}0.2635e^{j167.7^\circ} & 0.1345e^{-j153.7^\circ}\\ 0.1345e^{-j153.7^\circ} & 1\end{bmatrix} \tag{3}$$

-45-degree wire:

$$S_{m4}=\begin{bmatrix}1 & 0.5747e^{-j93.1^\circ}\\ 0.5747e^{-j93.1^\circ} & 0.8770e^{-j172.0^\circ}\end{bmatrix} \tag{4}$$

They have good agreement with the theoretical values (5) of above four reflectors.

$$S_1=\begin{bmatrix}-1 & 0\\ 0 & 1\end{bmatrix},\quad S_2=\begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix},\quad S_3=\begin{bmatrix}0 & 0\\ 0 & 1\end{bmatrix},\ \text{and}\quad S_4=\frac{1}{2}\begin{bmatrix}1 & -1\\ -1 & 1\end{bmatrix} \tag{5}$$

These show good polarimetric features of this developed system.

3. Tree Monitoring

Three measurements were performed on April 19, 2002 in spring with a few of fresh leaves, on May 28, 2002 in summer with very exuberant leaves and branches and on November 11, 2002 in autumn while fall of leaves, respectively. The configuration of targets area and a coordinate system are shown in Fig. 2, where T1, T2 and T3 are a broadleaf tree, a conifer and a short tree, respectively. Fig. 3 shows the targets area in spring, summer, and autumn, respectively.

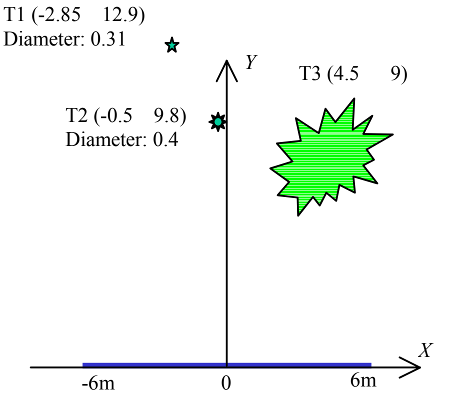

Fig. 2 Configuration of targets and a coordinate system

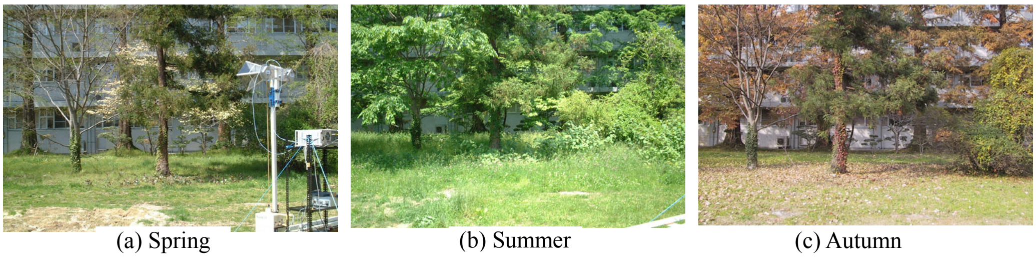
(a) Spring (b) Summer (c) Autumn

Fig. 3 Targets area

A 3-D reflectivity image can be reconstructed by using the dataset acquired on 2-D aperture. Synthetic aperture processing of diffraction stacking was employed to reconstruct the image by computing (6).

$$p(x,y,z)=\iint f(\tau,x_m,y_m,z_m)dx_m dy_m \tag{6}$$

where

$f(\tau,x_m,y_m,z_m)$: acquired data in time domain
(x_t,y_t,z_t): transmitter position
(x_r,y_r,z_r): receiver position
$p(x,y,z)$: migrated data in spatial domain

$$\tau=\frac{\sqrt{(x_t-x)^2+(y_t-y)^2+(z_t-z)^2}+\sqrt{(x_r-x)^2+(y_r-y)^2+(z_r-z)^2}}{v} \tag{7}$$

By using a pulse compression and the diffraction stacking, 3-D images are obtained. Fig. 4 shows the 3-D reconstructed images of HH, VH and VV by three experiments, respectively.

Analyzing the three polarimtric images of each measurement, we can find differences among the different polarizations. The HH image shows the reflection from trunks, some horizontal branches and ground clutter, the VH image indicates strong reflections from leaves, some slant branches and ground clutter, and the VV image illustrates the reflections from vertical trunks and branches. Comparing the corresponding images of the different measurement in Fig. 4, we can find the reflections from the trunks and the leaves are different by seasonal variation. There are stronger reflections in the images of the second experiment due to the exuberant branches and leaves in summer. Moreover, we can find a clear ground surface in autumn from Figs. 4(g), 4(h) and 4(i), which agree well with the real situation. Hence, we can assume that the main reflections were caused by the volume scattering due to the different volumes of leaves and branches in variant season. Different water content of trees in spring and autumn caused the slight differences of the reconstructed polarimetric images in spring and autumn. The different scattering performances of the variant trees in the different seasons can be observed generally.

4. Conclusion

We have used the developed ground-based polarimetric SAR system to monitor the trees changes with seasonal variation. We fund that the polarimetric SAR provides information about the radar target and the different scattering features of the variant trees in the different seasons can be detected by the polarimetric measurement generally. The test results showed the good polarimetric performance of the developed system. It was demonstrated that the broadband ground-based polarimetric SAR system has the advanced abilities and sensitivity for vegetation monitoring as well as environment studies. It has the potential to expose details of radar targets with additional information.

Acknowledgements

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Reference

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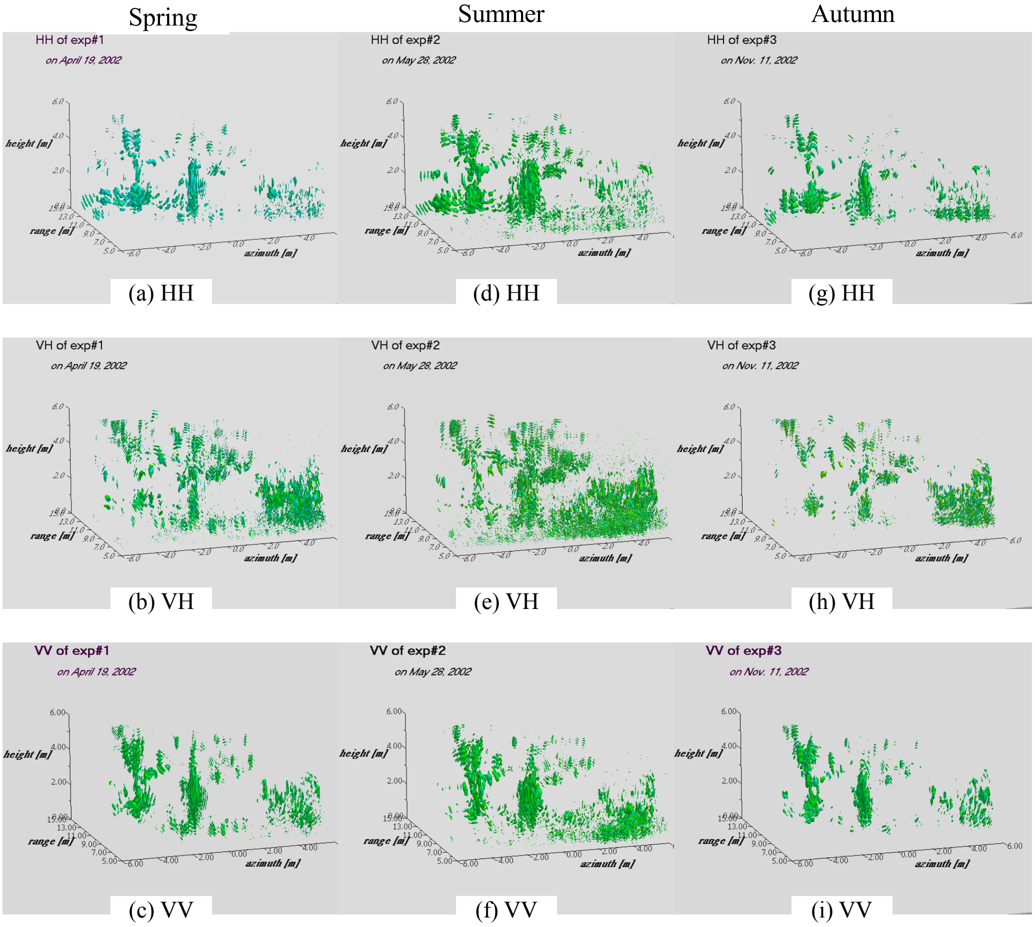

(a) HH (d) HH (g) HH

(b) VH (e) VH (h) VH

(c) VV (f) VV (i) VV

Fig. 4 Reconstructed three-dimensional images