Polarimetric Scattering Analysis for a Simplified Bridge Model on Water Surface

Ryoichi Sato [1], Yuta Takahashi [1], Yoshio Yamaguchi [2], and Hiroyoshi Yamada [2]
[1] Faculty of Education, Niigata University
8050, 2-no-cho, Ikarashi, Nishi-ku, Niigata, 950-2181 Japan
E-mail: sator@ed.niigata-u.ac.jp
[2] Department of Information Engineering, Niigata University, Japan

Abstract

This paper presents time-transient polarimetric analysis for a simplified bridge model on water Surface. We extend our previous 2D time-transient analysis to 3D polarimetric scattering problem. Here the Finite-Difference Time-Domain (FDTD) method is utilized. In addition to the time-transient feature, we focus on the generating mechanism of the volume scattering component with increase of the squint angle. So scattering power decomposition scheme is applied to the coherency matrix obtained by the polarimetric FDTD analysis.

Keywords: Water level estimation, time-transient analysis, radar polarimetry

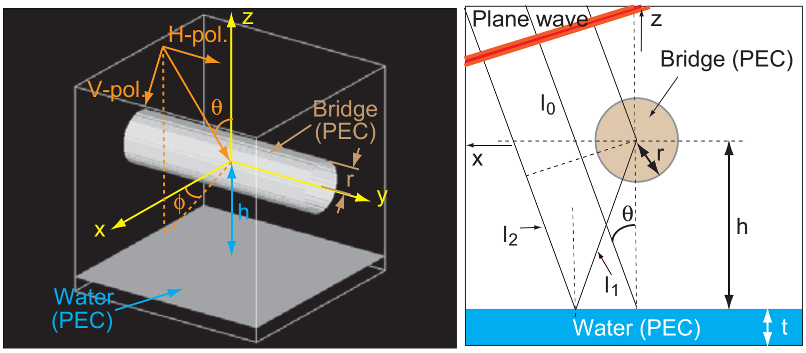
1. Introduction

Microwave remote sensing is a useful monitoring method for observing severe flooding area where one cannot carry out on-site inspections. It works well independent of weather condition, and day and night. In particular, polarimetric synthetic aperture radar (PolSAR) using fully or quad-polarimetric scattering components can provide us with detailed information on the scattering mechanisms from the target [1]-[5], so the PolSAR image analysis is one of the most powerful tools for precisely observing wide and severe disaster area.

Previous researches on water level estimation of risen river based on PolSAR image analysis have been indirectly executed by investigating the scattering mechanism of a bridge model over water surface [6], [7]. The bridge height inversion technique has been proposed in Ref. [7]. This simple technique may give us the accurate estimation result of the bridge height over water surface, once scattering process at the bridge-water structure is known. In Ref. [7], the bridge height is estimated by evaluating the slant range difference between single- and multi-bounce scatterings from various parts of the bridge. The slant range difference corresponds to the time delay of a transmitted pulse. Therefore, for further precise estimation of the water level of the river, it is very important to understand the accurate time-transient characteristics of scatterings from the bridge-water structure.

For the purpose, in Ref. [8], we have recently carried out time-transient scattering analysis for a 2D simple bridge model, which simulates a long steel bridge over water surface of the risen river, and consists of a perfect electric conductor (PEC) cylinder over infinitely long PEC plane. The study made clear how single- and multi-bounce scattering component contributes to the dominant time-transient response in the 2D bridge model.

In this paper, we extend the time-transient analysis to 3D polarimetric scattering problem, and investigate polarimetric scattering characteristics from a 3D bridge-water model, by utilizing the Finite-Difference Time-Domain (FDTD) method [9]. In addition to the time-transient feature, we focus on the generating mechanism of the volume scattering component with increase of the squint angle. So scattering power decomposition scheme [10]- [13] is applied to the coherency matrix obtained by the polarimetric FDTD analysis.



(a) (b)

Figure 1: Geometry of the problem. (a) 3D view (b) x-z plane

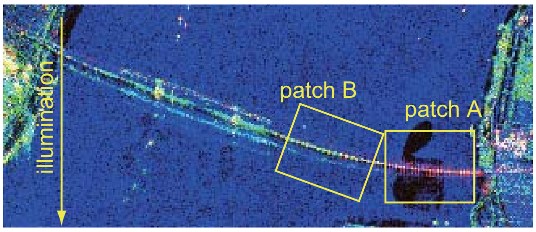


Figure 2: RGB color composite image acquired by ALOS/PALSAR around a big bridge in Shanghai. (Patch A) Normal illumination (Patch B) Oblique illumination

2. Scattering mechanism from a simple bridge model

We shall consider a transmitted plane wave impinges on a simple bridge model, which is composed of a long conductor circular cylinder (radius:r) over water (PEC) surface of the river, as depicted in Fig.1. Here, θ and ϕ are incident and squint angles, respectively. Also, h is the height of the bridge from the surface.

As a reference for oblique incident case, let us first consider fundamental scattering mechanism generated from the model when the radar illumination direction is normal to the bridge alignment.

2. 1 Path difference in slant range

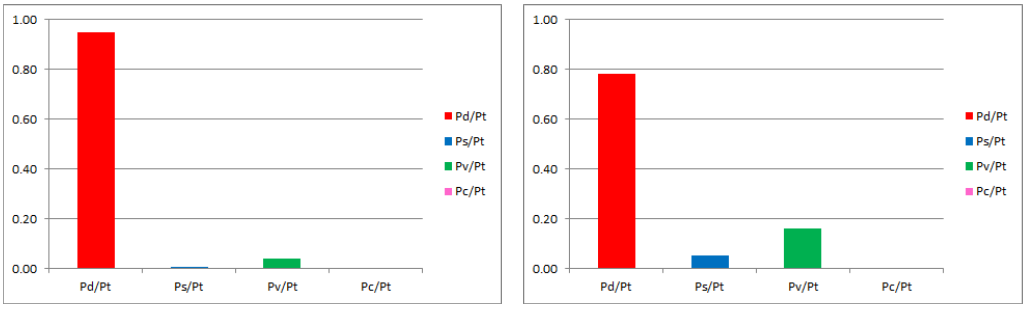
Fig.1(b) illustrates the geometrical ray path for single- and double-bounce mechanisms. The round-trip ray paths for the scatterings can be uniquely determined, and represented as $2(l_0 - h\cos\theta)$ and $2l_0$, respectively. It is obvious that the path length difference $l_1 + l_2$ becomes $2h\cos\theta$. For triple-bounce scattering, there are two types of ray paths, *i.e.* $2(l_0 + h\cos\theta)$ and $2(l_0 + h(1 - \cos\theta))$ [8]. These path length differences may be observed from the result of the PolSAR image analysis even for oblique illumination case.

2. 2 An example of PolSAR image analysis

Scattering component decomposition method is applied to the POLSAR data around a big bridge in Shanghai, China. Fig.2 shows the image obtained by using four-component scattering power decomposition [11]- [13] for the quad-PolSAR data set acquired by spaceborne ALOS/PALSAR system (L-band, 1.27GHz). The resolution of each pixel and the average size are 60 m by 60 m and 12 by 2 pixels. The off-nadir angle is 21.5°. The radar illumination direction is perpendicular to the alignment of the bridge. In the figures, the decomposed scattering powers are color-coded as follows. 1) Red is for double-bounce scattering P_d, 2) Green is for volume scattering P_v, and 3) Blue color is painted for surface scattering P_s. Patch A shows the region, in which the radar illumination direction is almost perpendicular to the

Table 1: Parameters in FDTD analysis

Analytical region	400×400×400 cells
Cell size Δ (= $\Delta x = \Delta y$)	0.02 m
Time step Δt	3.852×10^{-11} s
Incident pulse	Lowpass Gaussian
Absorbing boundary condition	PML (8 layers)



(a) 6-10 degs. (b) 11-15 degs.

Figure 3: Results of the FDTD analysis obtained by the scattering power decomposition. (a) Result for the average $\phi(=\phi_0) = 5°$ to $10°$ (b) Result for the average $\phi(=\phi_0) = 11°$ to $15°$

alignment of the bridge. Also, patch B shows the image for the oblique illumination case. For both normal and oblique casess in Fig.2, one can observe few strip lines around the bridge, which is utilized to estimate the height of the bridge over water surface by using Eq.(1) in Ref. [7], although the colors of the strip lines are different.

So, in the next section, we will carry out the polarimetric FDTD analysis for the simplified bridge model, to find out the reasen of the different strip colors.

3. FDTD polarimetric scattering analysis

We shall now consider time-transient scattering problem when Horizontal (H) or Vertical (V) linear polarized plane wave impinges on the simplified bridge model, which consists of a perfect electric conductor (PEC) circular cylinder on PEC plane, as shown in Fig.1(a). This model simulates a long steel bridge over water surface. To obtain the time-transient response from the model, the Finite-Difference Time-Domain (FDTD) method [9] is utilized. The height of the PEC cylinder from the water surface is set as h=4 m. The radius of the cylinder is r= 1 m. The incident or look angle is fixed at $\theta = \theta_0 = 25^o$, which is close to the small off-nadir angle of the ALOS/PALSAR data of Fig.2. The squint angle $\phi = \phi_0$ is variable from 1° to 15° here. The other fundamental FDTD parameters are shown in Table 1.

Figure 3 shows the result of PolSAR image analysis obtained by the execution of the four component scattering power decomposition [11]- [13]. Here, the ensemble average processing is carried out for each 5 degrees squint angular range (The data sets for 5 angles is averaged in each range), to statistically evaluate polarimetric scattering feature as actual PolSAR image analysis. In the figure, each decomposed power is normalized by the total power $P_t(= P_d + P_s + P_v + P_c)$.

Strong double-bounce scattering can be observed for both squint angular ranges. With increase of the squint angular range, one can see that the contribution of the volume scattering becomes large, whereas that of the surface scattering is small. This may be due to the fact that the cross-polarized component is enlarged when the squint angle becomes large. This tendency may be observed for further large squint angluar case.

Detailed consideration for larger squint angle case will be discussed in the presentation.

Acknowledgments

The authors express their sincere appreciations to JAXA, Japan, for providing valuable ALOS/PALSAR image data. This research was partially supported by a Scientific Research Grant-In-Aid (22510188) from JSPS, Japan, and Telecom Engineering Center (TELEC).

References

[1] Y. Yamaguchi, “Radar Polarimetry from Basics to Applications: Radar Remote sensing using Polarimetric Information,” IEICE, 2007.

[2] H. Mott,“Remote Sensing with Polarimetric Radar,” Wiley, 2007.

[3] W.-M. Boerner,“Introduction to Synthetic Aperture Radar (SAR) Polarimetry,” Wexford Press, 2008.

[4] J.-S. Lee and E. Pottier, “Polarimetric Radar Imaging: from Basics to Applications,” CRC Press, 2009.

[5] S. R. Cloude, “Polarisation: Applications in remote sensing,” Oxford Univ. Press, 2009.

[6] J.-S. Lee, E. Krogager, T. L. Ainsworth, and W.-M. Boerner, “Polarimetric analysis of radar signature of a manmade structure,” IEEE Geosi. Remote Sensing Letters, vol.3, no.4, pp.555–559, 2006.

[7] H. Wang at al. “Estimation of bridge height over water from polarimetric SAR image data using mapping and projection algorithm and de-orientation theory,” IEICE Trans. Commun., vol.E92-B, no.12, pp.3875–3882, Dec.2009.

[8] R. Sato, Y. Okubo, Y. Yamaguchi, and H. Yamada, “Time-transient Scattering Analysis for a Simplified Bridge Model on Risen Water Surface Using the FDTD Method,” Proc. of the 2010 Asia-Pacific Radio Science Conference (AP-RASC’10)(CD-ROM), F3a.5, Sept. 2010.

[9] A. Taflove and S. C. Hangness, “Computational Electrodynamics (3rd ed.),” Artech House, 2005.

[10] A. Freeman and S. L. Durden, “A Three-component scattering model for polarimetric SAR data,” IEEE Trans. Geosi. Remote Sensing, vol.36, no.3, pp,963-973, May 1998.

[11] Y. Yamaguchi, T. Moriyama, M. Ishido, and H. Yamada, “Four-component scattering model for polarimetric SAR image decomposition,” IEEE Trans. Geosi. Remote Sensing, vol.43, no.8, pp.1699-1707, Aug. 2005.

[12] Y. Yamaguchi, Y. Yajima, and H. Yamada, “A Four-Component Decomposition of POLSAR Images Based on the Coherency Matrix,” IEEE Geosi. Remote Sensing Letters, vol.3, no.3, pp.292-296, July 2006.

[13] Y. Yajima, Y. Yamaguchi, R. Sato, and H. Yamada, “POLSAR image analysis of wetlands using a modified four-component scattering power decomposition,” IEEE Trans. Geosi. Remote Sensing, vol.46, no.6, pp.1667-1673, June 2008.