3D SUBSURFACE VISUALIZATION BY SUPPRESSING GROUND REFLECTION AND DIRECT WAVE WITH BISTATIC GPR

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1. INTRODUCTION

Ground penetrating radar (GPR) is one of the promising tools for a monitoring of a subsurface, and gathers much attention, nowadays. Its applications to a landmine detection, a ground water monitoring and so on are reported [1][2], and extend to the subsurface monitoring of a moon [3]. Generally, an extraction and an analysis of a reflection from a buried target are main purposes for GPR. However, a ground reflection and a direct wave which propagates from a transmitting antenna to a receiving antenna directory are arisen as problems especially in the monitoring of a near-surface region. Because those amplitudes are larger than that of the target reflection, they often mask the target reflection and make an analysis difficult. The authors have developed a bistatic GPR system and propose its usage for a subsurface visualization without the ground reflection and the direct wave in this paper. In the proposed bistatic GPR system, the transmitting antenna whose position is fixed to one position radiates an incident wave, and the receiving antenna which scans a two dimensional horizontal plane over the subsurface receives the target reflection. The ground reflection and the direct wave are suppressed by using a Brewster angle and a frequency – spatial frequency domain filter (*f-k* filter), respectively. Then, a three dimensional radar image is constructed with a migration technique.

This paper mainly focuses on suppression methods of the ground reflection and the direct wave by the Brewster angle and the *f-k* filter. Firstly, a configuration of the proposed bistatic GPR system is simply described. Then, the suppression methods are presented. Finally, they are validated with a measurement to detect a buried object.

2. BISTATIC GPR SYSTEM

Fig.1 shows the bistatic GPR system which the authors have developed. This radar system is based on a vector network analyzer (VNA) and is a stepped-frequency radar system. A dual ridged horn antenna and optical electric field sensor (OEFS) are employed as the transmitting and the receiving antennas, respectively. An operational frequency range of this system is a range of 0.5–5.5 GHz. The transmitting antenna is fixed on an arbitrary place,

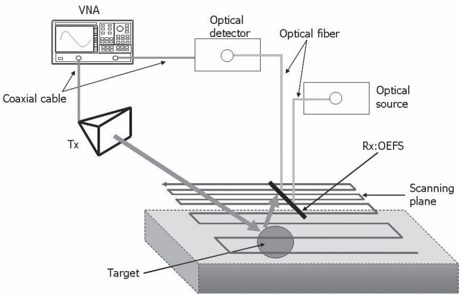


Fig.1. Bistatic GPR system using an OEFS as a receiving antenna.

and the receiving antenna acquires signals in every point on a grid alignment which is on a horizontal plane with a zigzag scanning. An acquired dataset is processed with a pulse compression and the migration technique. Then, the three dimensional radar image of the subsurface is constructed.

A flexibility of a location of the transmitting antenna is one of the important advantages of this system. It enables to utilize the Brewster angle which is explained in a next chapter.

3. SUPPRESSION OF GROUND REFLECTION AND DIRECT WAVE

3.1. Suppression of the Ground Reflection by Using Brewster Angle

When a propagation of a transverse magnetic wave (TM wave) is considered, a reflection coefficient of the electromagnetic wave at a boundary of two media is given as:

$$\Gamma = \frac{-\left(\varepsilon_2 / \varepsilon_1\right)\cos\theta_i + \sqrt{\left(\varepsilon_2 / \varepsilon_1\right) - \sin^2\theta_i}}{\left(\varepsilon_2 / \varepsilon_1\right)\cos\theta_i + \sqrt{\left(\varepsilon_2 / \varepsilon_1\right) - \sin^2\theta_i}} \,. \tag{1}$$

Here, the propagation from the medium with a relative permittivity of ε_1 to the other medium with the relative permittivity of ε_2 are considered, and θ_i is an incident angle. An interesting point here is that the reflection coefficient Γ becomes 0 with the incident angle θ_b which satisfies:

$$\theta_b = \tan^{-1}\sqrt{\frac{\varepsilon_2}{\varepsilon_1}} \,. \tag{2}$$

This angle is called as the Brewster angle [4]. As for the GPR, the problem can be considered as a reflection at a ground surface which is the boundary between the air and the subsurface whose relative permittivities are ε_1 and ε_2. Hence, the Brewster angle can be obtained from the relative permittivity of ε_2, because ε_1 is 1. In the proposed system, the relative permittivity is measured at the beginning, and the transmitting antenna is located to satisfy (2). Then, the reflection at the subsurface does not occur, and all the energy penetrates into the ground due to an effect of the Brewster angle. The foregoing is a methodology of the suppression of the ground reflection.

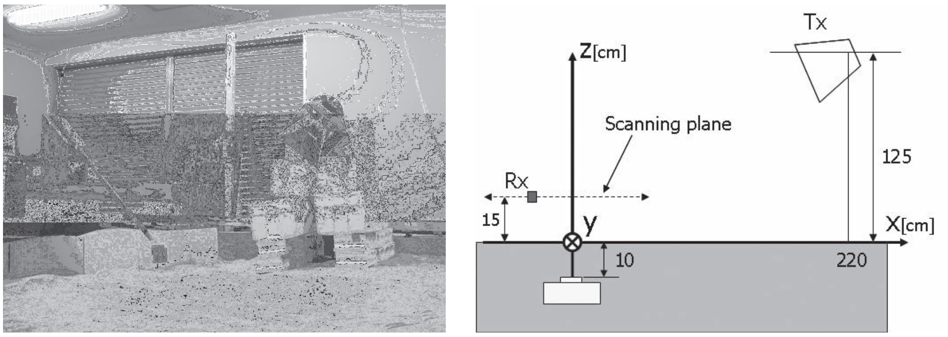
3.1. Suppression of the Direct Wave by Using *F-k* Filter

The *f-k* filter is utilized to suppress the direct wave component in this system [5]. Generally, the *f-k* filter utilizes a relationship between two domains : a time-space (*t-x*) domain and, their Fourier duals, the *f-k* domain. An apparent velocity of an incidence along a spatial sampling line, which is a velocity of the incidence in a direction of the spatial sampling line, corresponds to a slope of a spectrum in the *f-k* domain. By using this relationship, a separation of incident waves that arrive from different directions can be implemented.

In this system, signals are acquired in every point on the grid alignment which is on the two dimensional horizontal plane. The two dimensional scanning plane consists of a number of one dimensional scanning lines. Besides, the apparent velocity of the direct wave takes maximum and minimum values at both edges of the scanning line. At this time, the *f-k* spectrum of the direct wave distributes between two lines whose slopes are the maximum and the minimum apparent horizontal velocity. Thus, those slopes are estimated from positions of the transmitting and the receiving antennas firstly, then a filter to reject a spectrum between those two lines is designed and applied. This process is applied to every one dimensional scanning line, and the direct wave component is suppressed. It was confirmed that this method works effectively in a variable incident angle between 20 degree and 80 degree [5].

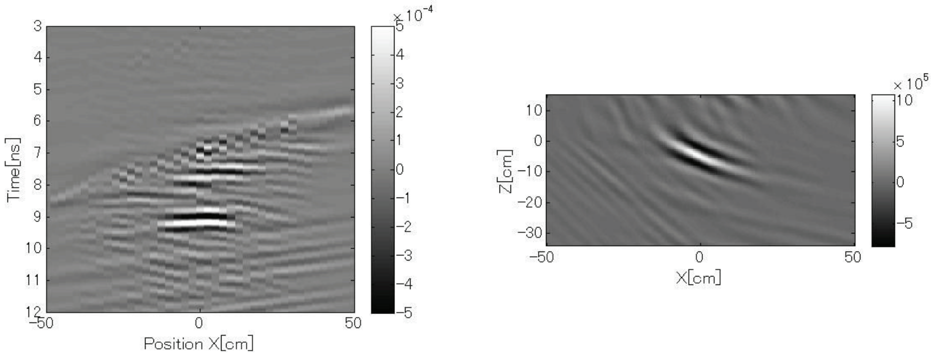
4. DETECTION OF BURIED OBJECT

In order to present a performance of this system, the measurement to detect the buried object was carried out in a sandpit. A scenery and a configuration of the measurement can be found in Fig.2. The sandpit is filled with dry and homogeneous sand. And, its relative permittivity is 4.0 which is measured with time domain reflectometry. The Brewster angle is estimated from this value, then the location of the transmitting antenna is determined to satisfy the Brewster angle. A landmine model of PMN2 was used as the target, and buried at a depth of 10cm.



(a) (b)

Fig.2. Bistatic radar measurement in the sandpit, (a) scenery and (b) configuration.



(a) (b)

Fig.3. (a) Radar profile along Y = 0, where *f-k* filter is applied. (b) Reconstructed vertical image.

A radar profile applied the *f-k* filter is found in Fig.3 (a). In this data, the ground reflection and the direct wave are effectively suppressed, and a higher amplitude around 9ns corresponds to a reflection from the target. Fig.3 (b) shows a vertical radar image processed with the migration technique. The reflection from the target can be clearly seen around X = 0. In contrast, the ground reflection does not appear on Z = 0. From this result, it is verified that the ground reflection and the direct wave are suppressed effectively, and the only reflection from the target is enhanced with the bistatic GPR system.

5. CONCLUSION

A reconstruction method of a subsurface image with a bistatic GPR system is proposed and verified with a measurement in this paper. A ground reflection and a direct wave component that are often arisen as an issue especially for a near-surface GPR are suppressed by using a Brewster angle and an *f-k* filter. Both of them are simple, and can have broad utility. Experimental results give the subsurface image without the ground reflection and the direct wave under a condition that a landmine model is buried at a depth of 10cm.

Specially, a suppression of the ground reflection is one of the challenging tasks for GPR. Thus, an application of the proposed bistatic GPR system can be an interesting approach of it.

[1] L. Qi, and M. Sato, "Estimation of hydraulic property of an unconfined aquifer by GPR," Sensing and Imaging, vol.8, no.2, pp.83-99, Sep. 2007.

[2] K. Takahashi, "Detection and localization of subsurface objects by ground penetrating radar," Ph.D. dissertation, Dept. Environ. Stud., Tohoku Univ., Sendai, Japan, 2006.

[3] T. Ono, A. Kumamoto, H. Nakagawa, Y. Yamaguchi, S. Oshigami, A. Yamaji, T. Kobayashi, Y. Kasahara, and H. Oya, "Lunar radar sounder observations of subsurface layers under the nearside Maria of the moon," Science, vol.323, no. 5916, pp.909 – 912, Feb. 2009.

[4] L. C. Shen, and J. A. Kong, "Applied electromagnetism," PWS Publishing Company, Boston, 1995.

[5] N. Hayashi, and M. Sato, "*F-k* filter designs to suppress direct waves for bistatic ground penetrating radar," IEEE Trans. Geosci. Remote Sens., vol.48, no.3, Mar.2010 (in press).