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# WAVELET ANALYSIS OF RANDOMLY REFLECTED ELECTROMAGNETIC WAVES OF SUBSURFACE RADAR

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## 1. Introduction

The technique of remote sensing using electromagnetic waves is required to develop for the detection of underground objects. A study of subsurface radar became popular in 1970's, and some of the radars were developed practically. However, each buried positions, shapes, characteristics of underground objects were not established with sufficient accuracy. In the recent years. most of studies of subsurface radars are concerning to radar signal processing.

We have realized that the difficulty of estimation of objects using electromagnetic waves is attributed to randomness and conductivity charasteristics of underground media. In the underground, there can be many stones and spaces besides targets, and unwanted scattered waves are received by antenna of radar system due to the electromagnetic wave reflection from the positions that have large variation of electric constants. In this study, we are viewing that unwanted scattered waves make the estimation of underground objects difficult. And by signal processing of the radar response, we have tried to cut them off and retrieve informations about underground targets.

Regarding scattering of electromagnetic waves in random media, we have carried out analysis using FDTD method in 1990's. and we found that the time response of subsurface radar has some reflected waves from individual unwanted scatterers in the underground. Therefore. the response of a radar can be assumed to be superimposed with unwanted scattered waves. The wavelet transform is formulated to the transform using a local wave as orthonormal basis function and in this paper, we have used it to decompose the response wave into individual reflected wave. A comparison between the wavelet analysis of homogeneous media and that of random media would show us a possibility of removing unnecessary reflected waves .

## 2. The wavelet analysis

In recent years, Fourier analysis is getting changed to wavelet analysis as a new numerical method of signal processing, and in the field of electromagnetic field theory there have been some reports in which wavelet analysis is applied. When $E(t)$ is a y-polarized electric field, the wavelet analysis of $E(t)$ is defined as,

$$(WE)(a,b) = \int_{-\infty}^{\infty} E(t)\phi_{a,b}(t)dt \tag{1}$$

$$\phi_{a,b}(t) = \frac{1}{\sqrt{a}}\phi\left(\frac{t-b}{a}\right) \tag{2}$$

where $\phi(x)$ represents a wave which exist in the local time domain, called wavelet. Especially, when $\phi(t)$ satisfy the following condition,

$$C_\phi = \int_{-\infty}^{\infty} |\hat{\phi}(\omega)|^2 \frac{d\omega}{|\omega|} < \infty \tag{3}$$

$\phi(t)$ is called an analyzing wavelet.

$$\hat{\phi}(\omega) = \int_{-\infty}^{\infty} \phi(t) e^{-j\omega t} dt \tag{4}$$

is the Fourior transform of $\phi(t)$.
If $\phi(t)$ is the analyzing wavelet, inverse wavelet transform is defined as,

$$E(t) = \frac{1}{C_\phi} \int \int (WE)(a,b) \frac{1}{\sqrt{a}} \phi\left(\frac{x-b}{a}\right) \frac{dadb}{a^2} \tag{5}$$

By varing $a(>0)$, we can obtain multiresolution analysis of wave phenomena, and detection of hided informations. Many functions such as Haar function have been proposed as wavelet functions. We have applied the Morlet type wavelet, because it is a smooth function like a reflected wave and our purpose is to analyse the reflected waves.
Morlet type wavelet is defined as,

$$\phi(t) = \frac{1}{\sqrt{2\pi}\sigma} exp(-\frac{t^2}{2\sigma^2}) \cdot exp(-j\omega_0 t) \tag{6}$$

where $\sigma$, $\omega_0$ are constants.

## 3. Simulation of subsurface radar

The simulation of subsurface radar is performed by computer program using FDTD algorithm. A pulse wave is radiated from a source antenna and scattered from random underground objects. The radar simulation model is shown in Fig.2. A target is a rectangular air gap whose size is 0.3m × 0.5m. The medium constants are homogeneous, defined as $\varepsilon_r = 4.0$ and $\sigma = 0.001$ in the underground, where $\varepsilon_r$ is the relative dielectric constant of the underground and $\sigma$ is conductivity constant of the underground. Random media model is shown in Fig.3. The medium constants are same as that of previous model, there are 256 unwanted scatterers with random relative dielectric constants and random positions as shown in Fig.3. The result of simulation for homogeneous media(Fig.2) is shown in Fig.3. From this figure, we can easily identify the reflected waves from a rectangular air gap. Next, the result of simulation for random media is shown in Fig.4. From this figure, it is difficult to diffenrentiate waves reflected from a object from that of air gap because the received waves are randomly disturbed.

## 4. Results

Results of wavelet analysis of each radar response for the models shown in Fig.2, Fig.3 are shown in Fig.6, Fig.7. By comparison with both the results, we can find out the region in which the unwanted scattered waves are vanishing as shown in Fig.7 in the region, a = 20 ~ 30, and this region is shown in Fig.8. Clearly, only waves reflected from an air gap remain in the signal.

## 5. Conclusion

We have presented in this paper, the preliminary results on the analysis of randomly reflected electromagnetic waves of subsurface radar. This may be considered as a first step of removing unwanted scattered waves from the random radar responses. We can also assume that unwanted scattered waves are smaller than reflected waves from an air gap, and we feel that the relation between the applied wavelet and reflected waves from an air gap is important to be considered.

A lot of simulation experiments are necessary to be considered in this regard. In future, we expect further development of signal processing for the removal of unwanted scattered waves using wavelet analysis of various random models.

## 6. References


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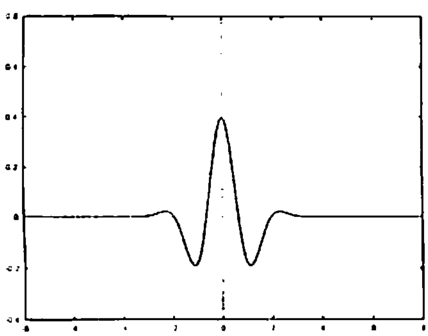

Fig.1 Morlet type wavelet $\phi(t)$

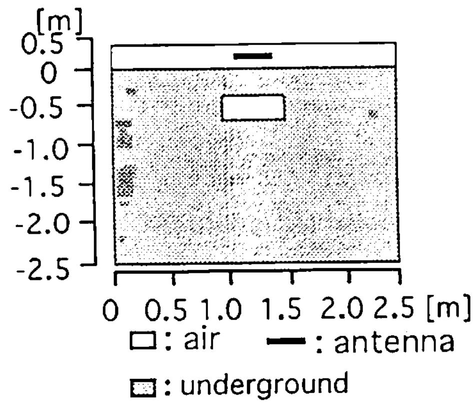


Fig.2 Simulation model of the homogeneous media for subsurface radars. ($\varepsilon_r = 4.0$, $\sigma = 0.001$)

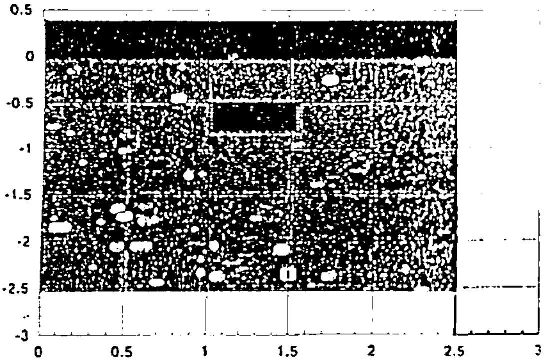


Fig.3 Simulation model of random media for subsurface radars. ($\epsilon_r$ = 4.0, $\sigma$ = 0.001)

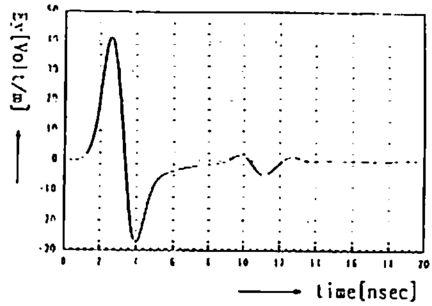


Fig.4 A result of FDTD analysis of homogeneous media(Fig.2).

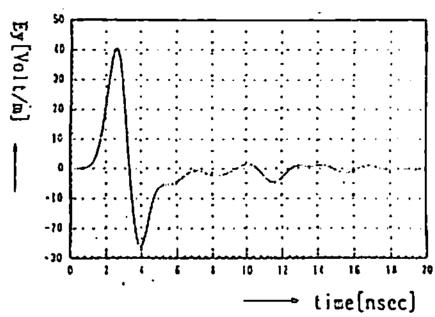


Fig.5 Result of the FDTD analysis of random media(Fig.3)

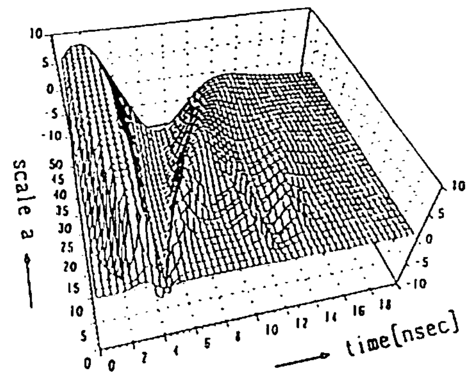


Fig.6 Result of the wavelet analysis of radar response (Fig.4).

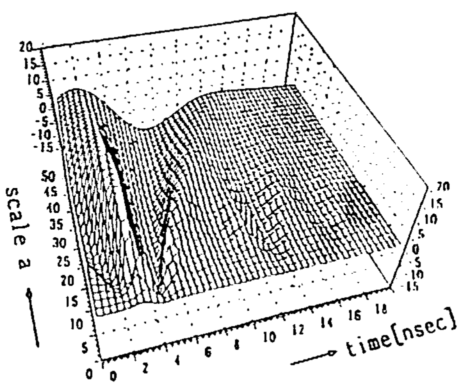


Fig.7 Result of the wavelet analysis of radar response (Fig.5).

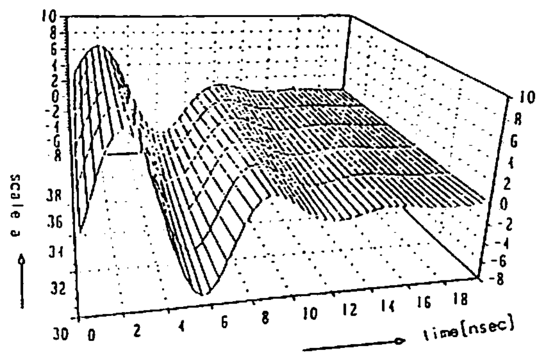


Fig.8 Wavelet analysis of randomly reflected waves, ($20 \leq a \leq 30$).