Calibration of Target Response for Time-Domain Feature Extraction

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Abstract

Waveform calibration of target response for time-domain feature extraction is proposed and is applied to a response from a complex object measured by a GPR. The result demonstrates that the waveform calibration of GPR data is significant for reliable target identification.

Keywords : Ground penetrating radar, Feature extraction

1. Introduction

Ground penetrating radar (GPR) is a useful sensor in searching for buried objects such as utility pipes and landmines in the ground [1]. However, it is still insufficient for accurate identification of buried objects. In order to use GPRs to identify buried objects, it is necessary to extract as much information from the GPR signal as possible concerning features of the target and to use the features effectively. As an incident pulse, a simple shape waveform such as a monocycle pulse with a sharp peak is convenient for time-domain feature extraction [2]. In actual situation, however, the pulse waveform is distorted by characteristics of transmitting and receiving antennas when the pulse is radiated and received by the antenna pair. Therefore, a calibration procedure that removes the antenna characteristic and makes the desired pulse waveform is necessary. Since the waveform distortion caused by the antennas is expressed as a convolution of the pulse generated in the transmitter and the impulse response of the antenna pair, the distortion can be eliminated by an inverse filtering operation in frequency domain. In our previous study, we proposed a method for calibration of the pulse waveform using a metal plate reflection [3][4]. In this study, we apply this method to actual experimental data obtained by the UWB-Vivaldi antennas with shield case that have a strong antenna coupling, and demonstrate that the waveform calibration of GPR responses is significant for reliable target identification.

2. Calibration of Target Response

For convenience, we shall briefly summarize the procedure of waveform calibration based on the inverse filtering operation described in the References [3] and [4]. Figure 1 shows monostatic radar signal measurement using a GPR system considered in this study. For simplicity, we assume that the surrounding medium is non-dispersive. This measurement can be expressed in terms of transfer functions, as illustrated in Fig. 2. Thus, the received signal can be expressed as

$$G(\omega) = H_{Rx}(\omega)H_{prof}(\omega)H_{targ}(\omega)H_{prob}(\omega)H_{Tx}(\omega)F(\omega) + H_{Rx}(\omega)H_{crs}(\omega)H_{Tx}(\omega)F(\omega)$$
(1)

where $H_{Tx}(\omega)$ and $H_{Rx}(\omega)$ are transfer functions of transmitting and receiving antennas, $H_{prof}(\omega)$ and $H_{prob}(\omega)$ are transfer functions of propagation paths between antennas and the target, $H_{crs}(\omega)$ represents antenna crosstalk, and $F(\omega)$ and $G(\omega)$ are spectra of incident and received pulses, respectively. The first term on the right hand side of Eq. (1) is a target response and the second is a crosstalk between the transmitting and receiving antennas. Measurements of the target response with a vector network analyzer allow us to measure the S parameter, and the S parameter of target response S_{targ} corresponding to Eq. (1) is expressed as follows:

$$S_{targ} = H_{Rx}(\omega)H_{prob}(\omega)H_{targ}(\omega)H_{prof}(\omega)H_{Tx}(\omega) + H_{Rx}(\omega)H_{crs}(\omega)H_{Tx}(\omega)$$
(2)

Under the backscattering condition $(H_{prof}(\omega) = H_{prob}(\omega) = H_{prot}(\omega))$, we can rewrite the Eq. (2) as follows:

$$S_{targ} = H_{ANT}(\omega) [H_{prot}(\omega)]^2 H_{targ}(\omega) + H_{ANT}(\omega) H_{crs}(\omega)$$
(3)

where $H_{ANT}(\omega) = H_{Tx}(\omega)H_{Rx}(\omega)$ is the total antenna characteristics to be eliminated. Since the second term of the above equation is antenna crosstalk, it can easily be determined from the measured response when there is no target.

Next, as a reference data for calibration, we introduce S parameter S_{metal} that corresponds to a flat metal plate reflection. After subtracting the antenna crosstalk, we have the following S parameters:

$$\widetilde{S}_{targ} = H_{ANT}(\omega) \left[H_{prot}(\omega) \right]^2 H_{targ}(\omega), \quad \widetilde{S}_{metal} = H_{ANT}(\omega) \left[H_{prom}(\omega) \right]^2 H_{metal}(\omega)$$
(4)

where $H_{metal}(\omega)$ is the complex scattering amplitude of the response from the flat metal plate and $H_{prom}(\omega)$ is the transfer function for the path between two antennas and the metal plate. In order to remove the effect of the antenna characteristics that causes undesirable waveform distortion, we now construct an inverse filter $H_{ANT}^{-1}(\omega)$ that can eliminate the antenna characteristics. Using Eq. (4), the inverse filter can be expressed as

$$H_{ANT}^{-1}(\omega) = \left(1 / \widetilde{S}_{metal}\right) \left[H_{prom}(\omega)\right]^2 H_{metal}(\omega)$$
(5)

By applying this inverse filter to measured GPR response, we can eliminate the effect of the antenna characteristics. Substituting the above expression into Eq. (4), we can obtain the transfer function of the target as follows:

$$H_{targ}(\omega) \left[H_{prot}(\omega) \right]^2 = -\left(\tilde{S}_{targ} / \tilde{S}_{metal} \right) \exp(-jt_0 \omega)$$
(6)

where t_0 is a linear phase constant that corresponds to time delay. Since the scattering transfer function for the target response is given by Eq. (6), we can obtain the target response g(t) for the desired incident waveform by using inverse Fourier transform.

$$g(t) = -\frac{1}{2\pi} \int_{-\infty}^{\infty} (\widetilde{S}_{targ} / \widetilde{S}_{metal}) F(\omega) \cdot \exp[j\omega(t - t_0)] d\omega$$
(7)

3. Evaluation of the Calibration Using Experimental Data

In order to evaluate the waveform calibration mentioned above, we apply it to measured data obtained by a laboratory experiment. The UWB-GPR antennas used for the measurement are Vivaldi antennas designed in our laboratory to detect and identify shallowly buried objects such as anti-personnel landmines and reinforcing bars in concrete structures. Figure 3 is a schematic diagram of the antennas. The identically shaped transmitting and receiving Vivaldi antennas are separated by 3.0 cm, and are held in place by a dielectric (PVC). The antennas are in a metal box (shield case) with one open end in order to suppress radiation to the sides and back. Each antenna element is designed for use at frequencies higher than approximately 1 GHz [2], and the inner wall of the shield case is loaded with a 1-cm-thick electromagnetic wave absorber to reduce internal resonance that causes strong antenna ringing. This antenna is usable from 1 GHz to 6 GHz, that is the intended band for our experiment.

As a model target with a complicated shape, we consider a plastic landmine. Figure 4 is a photograph of the landmine model employed in the measurement, which is a dummy of a Type-72 anti-personnel landmine. It has a bun-shape with the diameter of 7.8cm and with the height 4.0cm. The interior is hollow and lower half part is filled with silica sand instead of TNT powder. Figure 5 shows experimental setup of measurement. As the incident pulse with simple waveform, we employ a monocycle pulse given by differentiation of the Gaussian pulse. Figure 6 shows the pulse waveform. Figure 7 shows measured and calibrated pulse responses from the landmine model. In

this figure, we can see that the late time response is suppressed and dominant part of the response is corrected by the waveform calibration. From this result, we can get the confirmation that the waveform calibration applied here provides a good calibration result and is significant for accurate feature extraction.

References

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Fig. 1: Measurement of target response from the unknown object using GPR antennas. Tx and Rx are the transmitting and receiving antennas, respectively.

Fig. 2: Block diagram of the GPR measurement expressed in terms of the transfer functions.



(a) Schematic diagram of the antenna set.



Fig. 3: UWD-GPR antenna set with shield case used for experiments. Two identically shaped Vivaldi antennas held in place by a dielectric are used for transmitting and receiving antenna elements. (a = 100mm, b = 185mm, l = 137mm).



(b) Component parts.

Fig. 4: Plastic Dummy of Type-72 anti-

personnel landmine with rubber cap used in

the experiment. It has a bun-shape with a

diameter of 7.8 cm and height of 4.0 cm.



Fig. 5: Measurement of target response from a plastic landmine model shown in Fig. 4.



Fig. 6: Monocycle incident pulse used for experiments. (Once-differentiated Gaussian pulse)



Fig. 7: Waveform of the landmine reflection before and after the waveform calibration.