UNDERGROUND IMAGING USING IMPULSE ULTRASOUND AND AMPLITUDE CORRELATION SYNTHESIS PROCESSING METHOD

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Abstract

An amplitude correlation synthesis processing method was proposed for underground imaging. Two kinds of scanning method were considered to suit for the underground buried bodies and interfaces, respectively. In case there is no prior knowledge of whether the underground target to be imaged is buried body or interface, this paper discussed the discrimination of the type of the target. The discriminating method is proved by the comparison imaging results in both the results of numerical simulation and experiment.

Introduction

Underground imaging is an important technique for nondestructive archaeological exploration and underground pipes detection, etc.

In our previous work, an amplitude correlation synthesis processing (ACSP) method was proposed [1,2]. An electromagnetic induction type sound source is employed to radiate a powerful impulsive ultrasound into the ground. The echo signals reflected by the underground target are received by receivers in a linear array. The amplitudes and the polarities are derived according to the length of propagation path corresponding to processing position. The image magnitude of the processing position is calculated by ACSP, i.e., the amplitudes in every sub-array group is multiplied according to polarity condition, and all the conditional multiplication outputs are synthesized.

Because of the different propagation paths of ultrasound, two kinds of scanning method were considered. One is the point-by-point scanning which suit for the underground buried bodies with dimension near to the wavelength, that reflect the incident ultrasound as secondary point source [1]; the other is the interface-by-interface scanning which suit for comparatively large archaeological sites or the interfaces of different earth layers that reflect the incident ultrasound according to the shortest propagation path principle [2]. The satisfactory experimental imaging results verified the efficiency of the ACSP for both of the underground targets.

However, in many applications, there is no prior knowledge of whether the underground target to be imaged is buried body or interface. In this paper, the discrimination of the type of the target is discussed, in case the interface is imaged to be buried body by the point scanning method, or vice versa. Owing to the different propagating path, the unsuitable scanning method will cause a decrease of the picked out amplitudes, the maximum image magnitude will be smaller than that obtained by the correct scanning method. This suggestion is clearly proved by the comparison imaging results in both the numerical simulation and the experiment. Hence, underground cross-section can be processed by both of the scanning methods, then the target can be discriminated by comparing the absolute image magnitudes, and finally the image can be synthesized.

Imaging Methods

On the ground surface, a linear array of six receivers R_1-R_6 placed with equal intervals symmetrically about the sound source placed in the center of the array is employed to receive the echo signals reflected from the underground target. The amplitudes and the polarities corresponding to a calculating position are derived by delay time according to the propagation path. The image value of the position is calculated by ACSP that will be interpreted thoroughly in following section. Finally, the image of underground cross-section under the transceiver array is calculated by scanning the whole imaging area position-by-position.

Owing to the different propagating path brought forth by different kinds of underground target, the imaging method is different concretely in “signal derivation” and “scanning”. As to the underground buried bodies, the delay time is calculated by point reflecting path, while as to the underground interface, it is calculated by shortest reflecting path. Correspondingly, the whole image is scanned point-by-point by changing the lateral position and the depth for buried bodies, and interface-by-interface by changing the decline angle and the depth for interfaces, respectively.

Propagating path for different underground target

Fig. 1 (a) and (b) show the sound propagating path from the sound source T to one of the receivers R_1 in the linear array, reflected by an underground buried body and an interface, respectively. As shown in Fig. 1 (a), the distance between a calculating point *P* and the sound source T is defined as r_{po}, while that between *P* and the *i*-th receiver R_i is r_{pi}; as to Fig. 1 (b), because that the reflection from a calculating interface *F* can be equalized to a direct wave radiated from the mirror image source T’, the path length of sound propagation is defined as r_{fi}, i.e. the distance between T' and R_i.

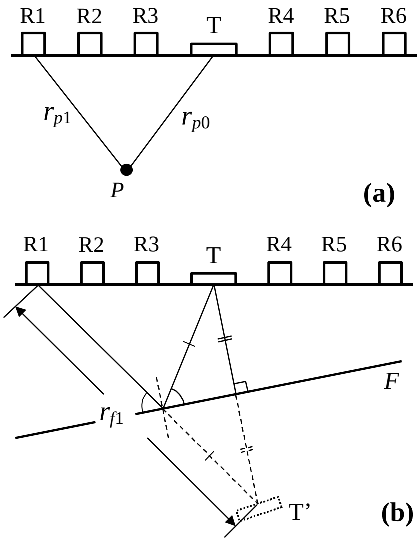


Fig.1 Sound propagating path reflected by (a) underground buried body; (b) underground interface

Amplitude correlation synthesis processing

Fig.2 shows the block diagram of ACSP. Where the shadowed part, *Signal Derivation*, is different for point-by-point scanning or interface-by-interface scanning.

The point-by-point scanning for imaging the buried bodies picked out the signal at the delay time corresponding to the calculating point *P* as

$$a_{pi} = s_i\left(\frac{r_{pi} + r_{po}}{c}\right) \qquad (i = 1,\ldots,6)\ , \qquad (1)$$

where c is the velocity of the underground longitudinal wave. As to the interface imaging, the amplitude and the polarity of each channel signal at the delay time corresponding to the calculating interface *F* is picked out as

$$a_{fi} = s_i\left(\frac{r_{fi}}{c}\right) \qquad (i = 1,\ldots,6)\ . \qquad (2)$$

Then, the 6 signals picked out by corresponding delay times are rearranged into 20 groups concluding any combination of 3 signals. Finally, the image magnitude at the calculating position is derived by the summation of the 20 outputs of Conditional Multiplication of 3 signals.

$$H = \left|\sum_{i<j<k} \mathrm{CM}\left(a_i, a_j, a_k\right)\right| \quad (i = 1,\ldots,4;\ j = 2,\ldots,5;\ k = 3,\ldots,6)\ , \qquad (3)$$

where $\mathrm{CM}(a_i,a_j,a_k)$ denotes the conditional multiplication function shown in Fig. 2 (b), that multiplies the amplitude of the 3 signals, and the polarity of its output is +1 when all the polarities of the 3 signals are +1, –1 when all of them are –1, and 0 when at least one of the amplitudes is 0 or its polarity is different from others.

$$\mathrm{CM}\left(a_i, a_j, a_k\right) = \begin{cases} a_i \cdot a_j \cdot a_k, & \left(\mathrm{sgn}(a_i) = \mathrm{sgn}(a_j) = \mathrm{sgn}(a_k)\right) \\ 0, & \text{others} \end{cases}\ . \qquad (4)$$

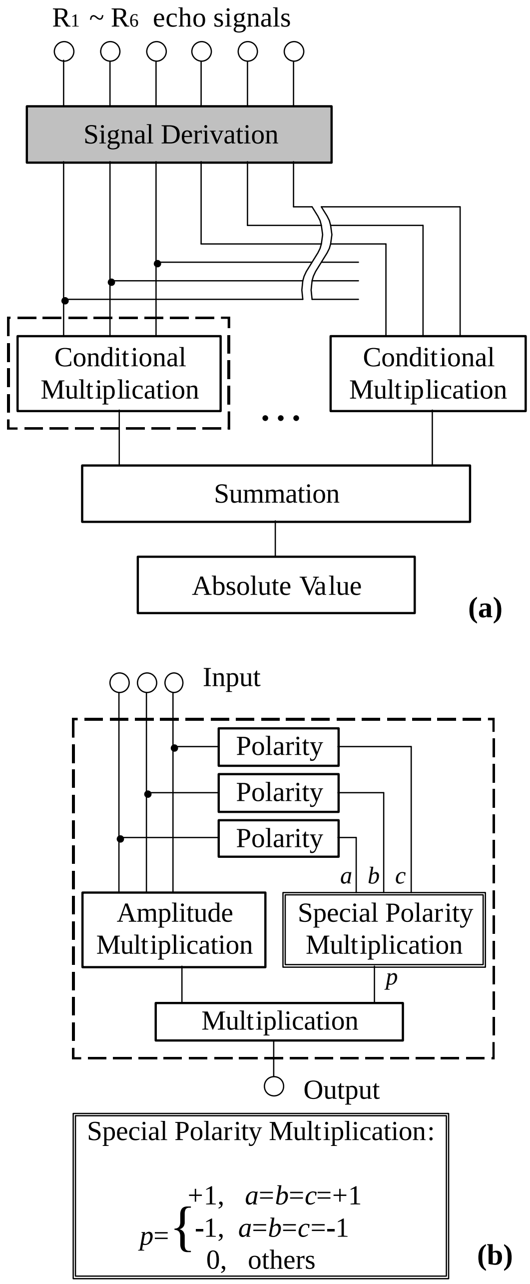


Fig.2 (a) Imaging procedure of ACSP and (b) processing of conditional multiplication

Discrimination of the underground target

The ACSP method can be easily explained that if the picked out signals have large amplitudes and take same polarities, the image magnitude of the calculating point (or the calculating interface) will be large. Therefore, if the scanning method (point scanning or interface scanning) suits for the type of the underground target (buried body or interface), all the 6 signals picked out will be large and with same polarities, that brings forth a large image magnitude, when the calculating position matches with that of the underground target.

On the other hand, if the received signals be treated by different scanning method, there is not any position corresponding to which all peak of echo signals can be picked out. Because the difference of reflecting path will introduce a shift of the delay time. The shift may be small than half of the wave length that makes several of the picked out signals take same polarity but not the maximum amplitude, which may introduce a blurred image. I.e. the buried body may be imaged to a blurred interface by interface scanning, while the interface be imaged to be a blurred buried body by point scanning.

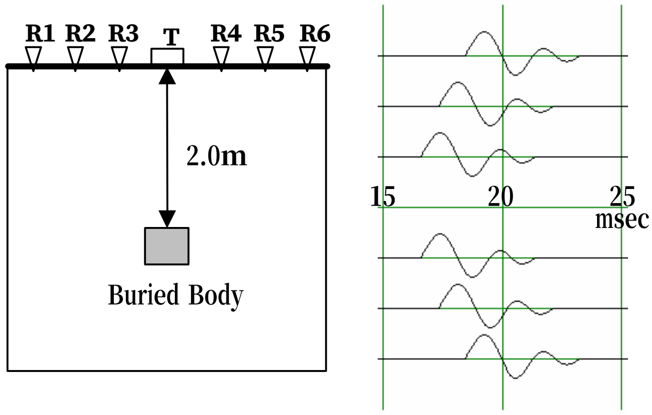
In case there is no prior knowledge on whether the target to be imaged is a buried body or an interface, the discrimination of the underground target is necessary. According to the former analysis, because the shift of delay time calculated by unsuitable scanning method will cause a decrease of the picked out amplitudes, the maximum image magnitude will be small than that be imaged “correctly” by the suitable scanning method. Therefore, in the application, the underground cross-sectional display can be processed with the two type of scanning method respectively, then the target be discriminated by comparing the absolute image magnitude.

Numerical Simulation

Two kinds of underground target are taken into consideration, a buried body just under the sound source, and an interface parallel to the receiver array, respectively. Both the depths are assumed to be 2 m. Similar to the experimental conditions, the interval between receivers is set to be 0.5 m, and the sound velocity to be 235 m/s.

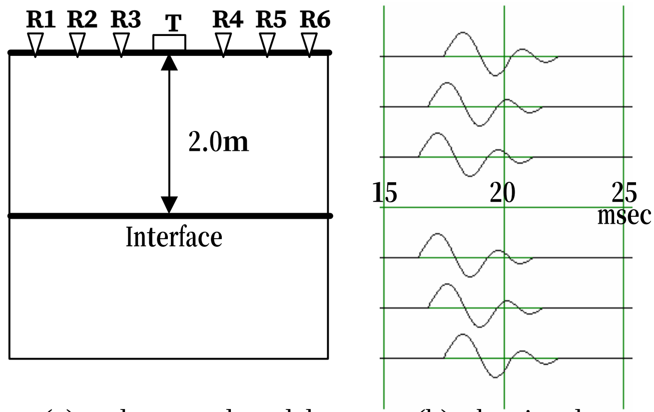
Fig. 3 and Fig. 4 show the underground model and the simulated reflect signals of a buried body and an interface, respectively. Neither noise nor direct wave is taken into consideration. The signals are assigned with corresponding delay times, based on a basic echo signal simulated according to the properties of the electromagnetic induction sound source and the propagation in the ground [2]. The difference of delay times to every receiver between the point reflecting and the interface reflecting is clearly shown in Fig. 3 (b) and Fig. 4 (b), respectively.

Fig. 5 (a) and (b) show the results of the buried body shown in Fig. 3 (a) imaged by point scanning and interface scanning, respectively. The images are displayed by five kinds of colors. Where the relative image magnitudes of 0 dB~-3 dB, -3 dB~-6 dB, -6 dB~-10 dB, -10 dB~-20 dB, and less than -20 dB compared to the maximum value in the entire imaging area are shown from white to black, respectively. As shown in Fig. 5 (a), because the point scanning picks out the maximum peak of echo signals when the calculating point matches with the position of simulated buried body, large image magnitude is derived clearly. Comparatively, Fig. 5 (b) shows a blurred interface at the same depth of the simulated buried body, owing to the difference of the time delay between point reflecting and interface reflecting. The difference of the image magnitude of the two images is greater than 6 dB, which is sufficient to discriminate the type of underground target clearly.



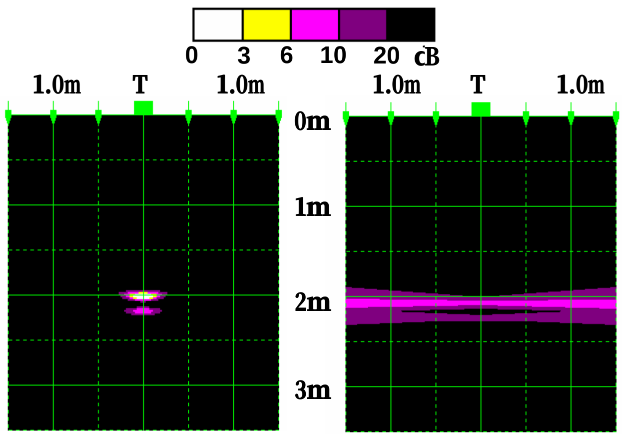
(a) underground model (b) echo signals

Fig. 3 Simulation model of buried body



(a) underground model (b)echo signals

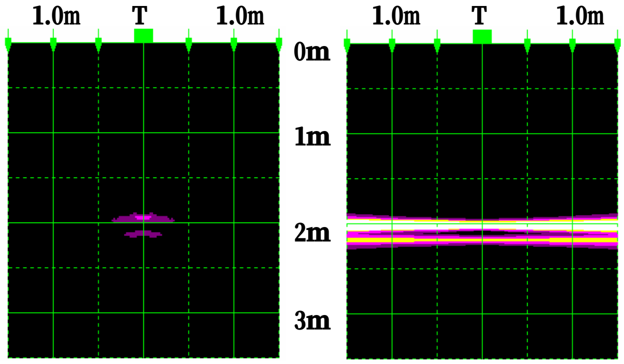
Fig. 4 Simulation model of interface



(a) point scanning (b) interface scanning

Fig.5 Simulation imaging result of buried body

In Fig. 6 (a) and (b), the imaging results of underground interface shown in Fig. 4 derived by point scanning and interface scanning are shown, respectively. Similarly, the suitable scanning method gives larger image magnitude with about 10 dB difference.



(a) point scanning (b) interface scanning

Fig.6 Simulation imaging results of interface

Experiment

Fig. 7 shows the measuring system, where an electromagnetic induction type sound source and the piezoelectric acceleration receivers are employed in the linear array, with interval of 0.5 m. The main frequency of impulse wave radiated from the sound source is set to be 460 Hz.

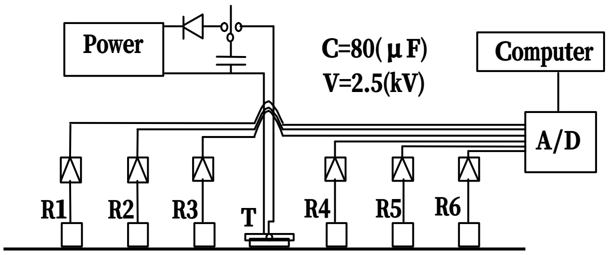


Fig. 7 Measuring system

The measurements are taken place in a sand bath built above the KANTOU loam layer. The velocity of the longitudinal wave in the specimen sand field is measured to be 235 m/s. A concrete block (0.3m*0.3m*0.3m) buried 2 m deep in the sand and the interface of the specimen sand field and the KANTOU loam layer are employed as the two kinds of underground targets, respectively.

As an example, the echo signals reflected from the 2 m depth concrete block is shown in Fig. 8. Fig. 9 and Fig. 10 show the imaging results of the buried body and the interface, respectively. Both are imaged by two scanning method for comparison. Though there are many other waves besides the echo signals reflected from the target, ACSP gives clear images at the position of the underground target. And the comparison results derived by two kinds of scanning show that the underground target can be discriminated easily with comparatively sufficient large magnitude derived by suitable scanning method.

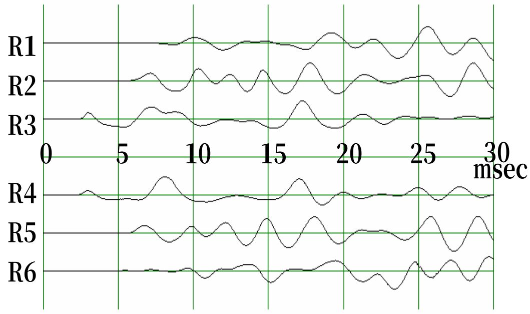
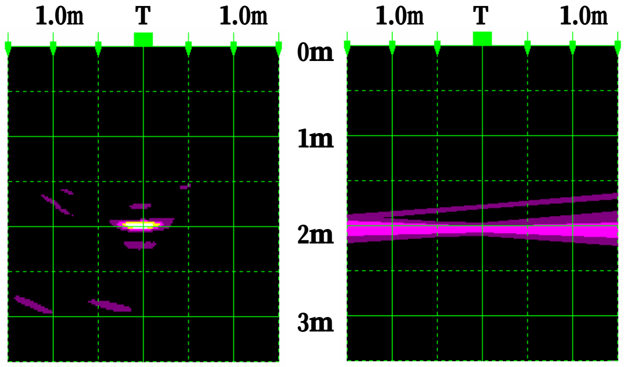
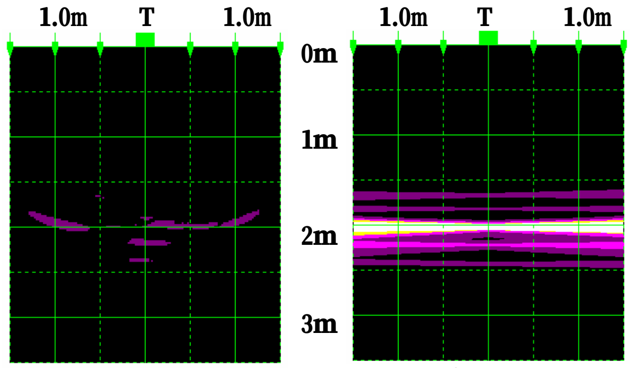


Fig. 8 Example of echo signals from buried body



(a) point scanning (b) interface scanning

Fig.9 Imaging results of buried body



(a) point scanning (b) interface scanning

Fig.10 Imaging results of interface

Conclusion

By using impulse ultrasound and amplitude correlation synthesis processing, both the buried body and the interface can be imaged satisfactorily. The underground target can be discriminated easily by comparing the images derived by two kinds of scanning respectively, due to the suitable scanning method provides larger image magnitude with over 6 dB difference.

References

[1] L. Tao, T. Tanaka, T. Watanabe, and S. Motooka, “Ultrasonic underground imaging using amplitude correlation synthesizing method,” Jpn. J. Appl. Phys., vol. 38, pp. 3148-3153, 1999.

[2] Y. Matsuo, L. Tao, T. Watanabe, and S. Motooka, “Imaging of underground interface using impulse ultrasound and amplitude correlation synthesis processing method,” Jpn. J. Appl. Phys., vol. 41, pp. 3539-3544, 2002.