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Non contact acoustic imaging method in the extremely shallow underground using optimum frequency range method by SLDV

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ABSTRACT

We propose a method of distinguishing a buried object using the frequency response range of the corresponding to the vibration velocity. Air-borne sound and a Scanning Laser Doppler Vibrometer are used for non contact acoustic imaging in the extremely shallow underground. Flat speakers that have a sharp directivity are used as vibration sources. Plastic container, hollow steel can, unglazed pot and stone are used as buried objects and they are buried in the sand (particle size is about 200-300um) about 2cm depth. First, noise waves are used for the confirmation of the buried object's frequency response range. The ground surface imaging result by SLDV is used to confirm the position of the buried objects. To confirm the frequency range, the difference of the vibration velocity is used. The frequency response range of the buried object is shown by a brightness mode image. And next, burst waves are emitted again to make a clear image. The frequency of the burst waves is set near the frequency response range. Finally, the buried object's frequency response range is checked again by the same way. The clear image is made by using the optimum frequency. We confirmed the frequency response range of each buried objects. From the indoor experimental results, the response range of the plastic container was distinctly different from the result of unglazed pot. The difference of the frequency response range of each buried object seems to depend on the difference of their resonance frequency.

INTRODUCTION

A sound wave vibration and a Scanning Laser Doppler Vibrometer (SLDV) are used for a method of exploring and imaging an extremely shallow underground [1][2][3]. The target is mainly a plastic antipersonnel land mine. Therefore, the exploration depth is assumed to be about 10 cm. In our previous study, we confirmed that a buried object showed a response range of specific frequency [2][3]. In this paper, plastic containers, a hollow steel can, a stone and an unglazed pot are used in the experiment. The optimum frequency response range method (OFR method) is proposed for distinguishing the buried object and making a most suitable image.

EXPERIMENT METHOD USING SLDV

Outline of experiment

The fundamental concept of the exploration method using the SLDV (Polytec Corp, PSV400-H8) is shown in Fig. 1. SLDV measures the vibration velocity of ground surface excited by sound wave caused from vibratory source. The vertical direction vibration velocity of the ground surface is measured by SLDV. The acoustic impedance of a buried object is distinctly different from that of the soil used as the propagation medium. Therefore, the buried object affects the propagation of vibration in the soil. This effect can be detected on the ground surface if there is the buried object near the ground surface. This time, two flat speakers (FPS Corp, 2030M3P1R) that have a sharp directivity are used for a vibration source. To generate a slow wave [4], flat speakers are inclined by about 20° [5].

Experimental Setup

The sand tank (110 × 135 × 50 cm^3) in our laboratory that had been filled with sand of uniform particle size (200 to 300 μm) was used for this experiment. Figure 2(a) shows the scan area size (27cm × 32cm). Plastic containers (11 × 11 × 6 cm^3, hollow: 80g, filled with sand: 825g, and filled with sugar: 540g), the hollow steel can (dia. 8.5 × 8 cm^3, 70g), the stone (5.5 × 6.5 × 2.7 cm^3, 210g) and the unglazed pot (top dia. 12 × 4 × bottom dia. 4 cm^3, 225g) are used as a buried object. The unglazed pot was buried upside down. Buried objects are shown in Fig. 2(b)-(e). The depth of buried objects is 2 cm. Output waves are the white noise (duration time is one second) and the burst wave (duration time is 0.2 second).

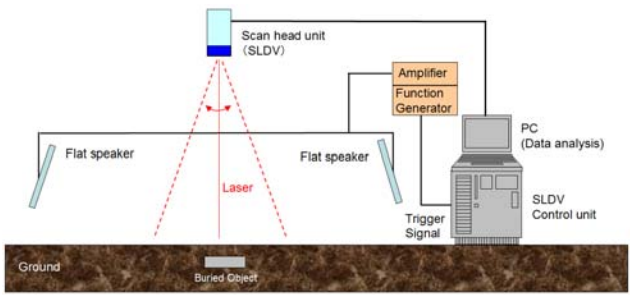

Figure 1. Fundamental concept of exploration method using SLDV

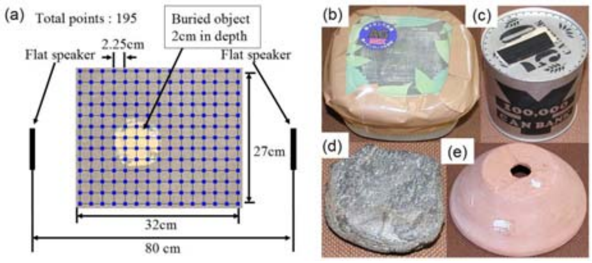

Figure 2. Experimental setup and buried objects. (a)scan area size, (b) Plastic container, (c) Hollow steel can, (d) Stone, (e) Unglazed pot

IMAGING METHOD OF THE OPTIMUM FREQUENCY RANGE

Measurement of vibraton velocity

When a response frequency band of the buried object is unclear, it is necessary to extract a response frequency band in reference to the vibration velocity to be provided by SLDV roughly. Therefore, the ground surface is vibrated by white noise sound including various frequencies first, and the vibration velocities are measured as two dimensionally (a measurement point is called a scan point, and the vibration velocity is recorded as data by every frequency). When a response frequency band is already known, the burst wave is used.

Standardization of frequency response range

To make clear the well vibrating part, average vibration velocity of all scan point from is deducted from vibration velocity every frequency in each scan point. However, even if the vibration velocity is small, the case that the relative difference with the average depending on the frequency is big is thought about. Therefore, the deducted result is divided by the vibration velocity of each scan point every frequency and standardized so that a relative difference with the average is plain. The relative vibration velocity difference from average vibration velocity can be expressed for the maximum with 1 by this calculation. The vibration velocity is standardized by the following equation.

$$D(x,y,\omega) = \frac{E(x,y,\omega) - A(\omega)}{E(x,y,\omega)} \qquad \cdots (1)$$

D(x,y,ω) is a standardizion results of the vibration velocity difference every frequency in each scan point. *A(ω)* is average vibration velocity of all scan points. *E(x,y,ω)* is vibration velocity every frequency of each scan point. Figure 3(a) is an example of *E(x,y,ω)* and *A(ω)*. In this case, *E(x,y, ω)* is the data of the buried position (plastic container). Figure 3(b) is an example of *D(x,y,ω)*. The strong responses of the frequency are used as a brightness image when the vibration velocity of this standardization result is more than the threshold value (usually 0.5).

Imaging by each frequency band

Using *D(x,y,ω)*, the candidates of the response frequency band of the buried object are searched. The value of *D(x,y,ω)* which showed values more than the threshold is integrated by equation(2). The threshold is usually around 0.5 that is the half value of the maximum of *D(x,y,ω)*, but when a relative vibration velocity difference is small, the threshold value will be changed generally.

$$G_n(x,y) = \int_{f_s}^{f_e} D(x,y,\omega)d\omega \qquad \cdots (2)$$

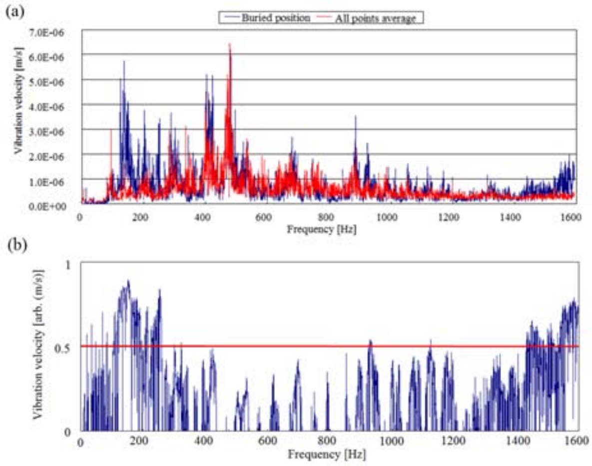

Figure 3. An example of vibration velocity vs. frequency (a) Comparison between the buried position (blue line) and all points average (red line), (b) Standardization result. Red line shows the threshold value for brightness imaging and OFR method.

Here, $G_n(x, y)$ is the integral of the vibration velocity difference at each scan point, f_s and f_e is the start and end frequency of the calculation as shown in Fig.4. In this stage, wide frequency range for integration is not good, because many noises are included. For extreme shallow underground imaging, about 200Hz is appropriate range. Using $G_n(x,y)$, underground images are made by each frequency range. When several points where integral calculus value is big then make the adjacency (more than normal two points), the part is imaged as a clear reply. The clearest resoponse point extracts provided image data as a criterion by the number of adjacent points and a total of the integral calculus value. Figure 5 shows an example of the image of each frequency band. From these images, the buried object can be identified under 400Hz. But more than 400Hz, it is not possible to find.

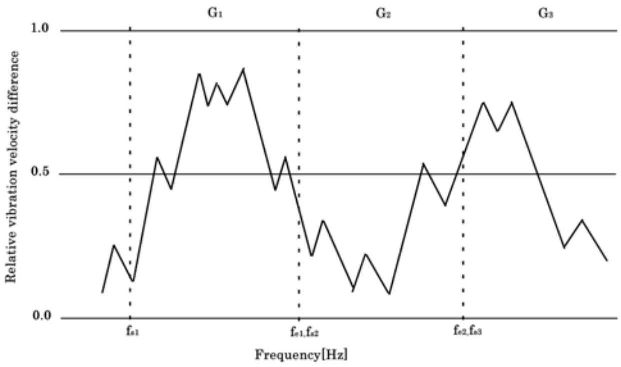

Figure 4. A setting example I : Start and end frequency for integral calculus equation (2).

Extraction of the optimum frequency range

The average of the vibration velocity every frequency of several points on the point where showed a clear response (The part which several points where integral calculus value is big are next to) is calculated. And then, using a difference with the average vibration velocity every frequency of all scan point, the standardization that is similar to an equation (1) is performed （This time between the average values is calculated）.

$$C(\omega) = \frac{B(\omega) - A(\omega)}{B(\omega)} \qquad \cdots (3)$$

Here, *B(ω)* is average vibration velocity of several points on the area that showed a clear resonse. *C(ω)* is the result of the standardization of a relative vibration velocity difference. The optimum response frequency band is decided by the relative vibration velocity difference *C(ω)*. First the threshold value will be set. The start and end frequency of the integral calculus will be decided by the range where several points of the relative vibration velocity difference is bigger than the threshold. If there were many such a range on the frequency axis, the product of the length and the integral value of *C(ω)* is used as a criterion. Best image can be made using the optimum frequency range by performing an integral calculus calculation by the equation (2) again (as shown in Fig.6). After finding the optimum frequency range, clearer image may get by using the burst wave with the frequency of the optimum frequency band. Figure 7 shows an example of the imaging result by OFR method.

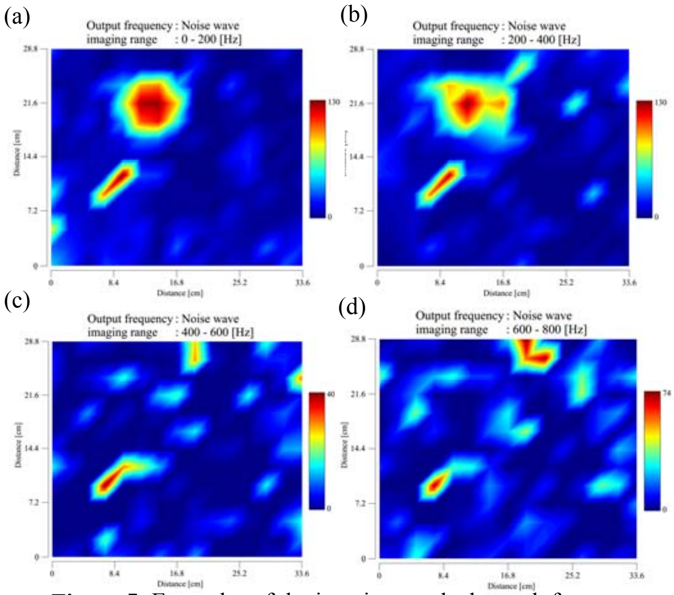

Figure 5. Examples of the imaging results by each frequency band(buried object is a hollow plastic container). (a) 0 - 200 Hz (b) 200 - 400 Hz (c) 400 - 600 Hz (d) 600 - 800 Hz

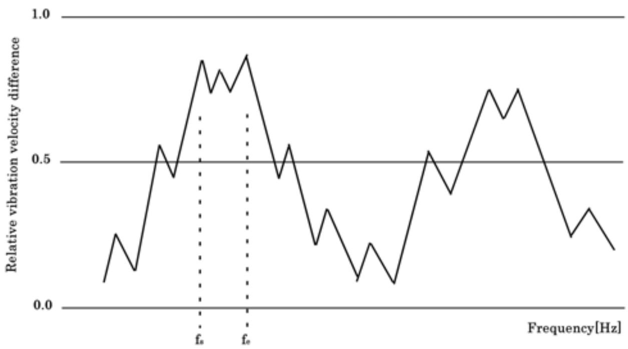

Figure 6. A setting example II : Start and end frequency for integral calculus equation (2).

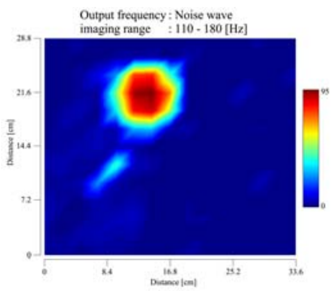

Figure 7. An example of the imaging result by OFR method (buried object is a hollow plastic container). Frequency range is 110-180Hz.

EXPERIMENTAL RESULTS

Brightness image of frequency response range

Before applying OFR method, the frequency response range of buried object is examined by using the brightness image [3]. The brightness imaging results after standardization of each buried objects are shown in Fig. 8. The response ranges of the frequency of the hollow plastic container and the plastic container filled with sand are shown at 100 to 200Hz. The response range of plastic container filled with sugar is shown at 150 to 250 Hz. This result is near the response range of the hollow steel can. On the other hand, the response range of the stone is shown at 1050 to 1100 Hz and 1200 to 1300 Hz and the unglazed pot is about 1000 Hz. Results of the stone and the unglazed pot is distinctly different than result of other buried objects. Therefore, it is thought that the resonance frequency affect the response range of the frequency of the buried object.

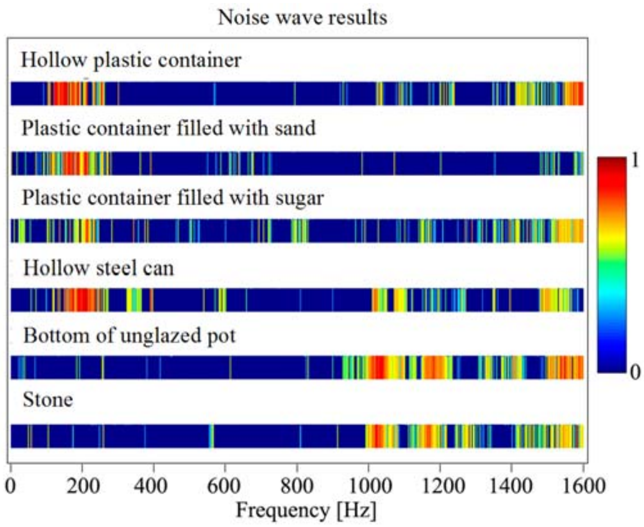

Figure 8. Brightness images of the frequency response range by the noise wave [3].

Optimum frequency image of each buried objects

Hollow plastic container‥Figure 9 shows the experimental result of OFR method. In this case, 150Hz burst wave is used. From the resultant figure, we can see the clearer image than the image of the noise wave.

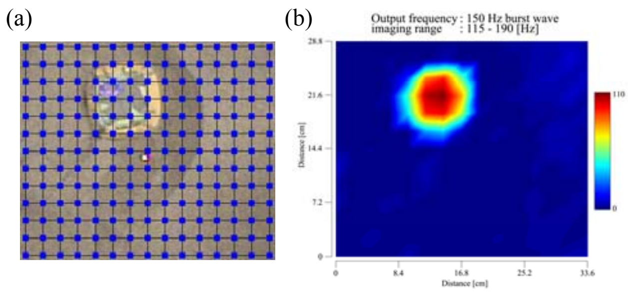

Figure 9. A hollow plastic container, 150 Hz burst wave results, (a) Buried position by CCD camera (b) Imaging result by OFR method : 115 - 190 Hz

Plastic container filled with sand‥The heaviest target in this experiment and in this case, the acoustic impedance is almost same with the surrounding media. Comparing the hollow one, the resultant image is smaller, but we can see clearly the buried object and its burid position.

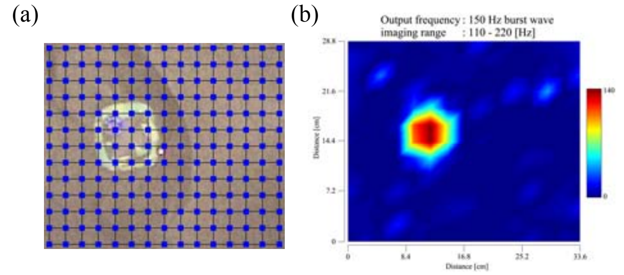

Figure 10. A plastic container filled with sand, 150 Hz burst wave results. (a) Buried position by CCD camera, (b) Imaging result by OFR method : 110 - 220 Hz

Plastic container filled with sugar・・Sugar is used because the specific gravity is almost same wiht trinitorotoluene. Like as the sand, it looks the whole container tends to be hard to vibrate because of its weight.

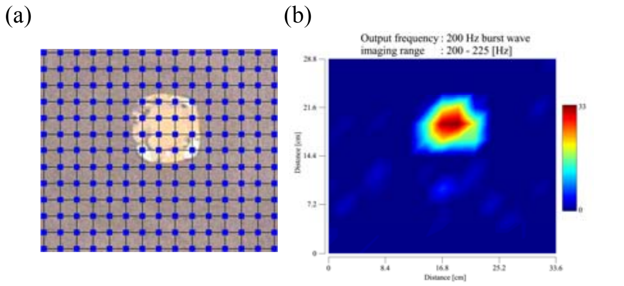

Figure 11. A plastic container filled with sugar, 200 Hz burst wave results. (a) Buried position by CCD camera, (b) Imaging result by OFR method : 200 - 225 Hz

Hollow steel can・・A hollow steel can is a one of the easy target for SLDV. The reason is the acoustic impedance is very different from the surrouding media. Therefore, the resultant image is almost same as the SLDV's velocity image.

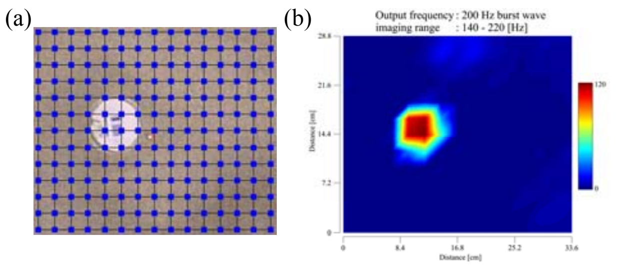

Figure 12. Hollow steel can, 200 Hz burst wave results. (a) Buried position by CCD camera, (b) Imaging result by OFR method : 140 - 220 Hz

Unglazed pot・・As shown in Fig.13(a), only 4 point is on an unglazed pot directly. In such a case, it is difficult to find by SLDV's velocity image only. But using the OFR method, we can find the unglazed pot at its buried position.

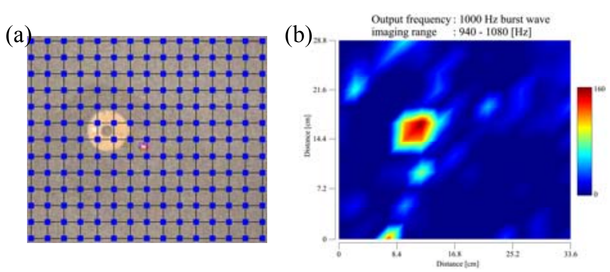

Figure 13. An unglazed pot, 1000 Hz burst wave results. (a) Buried position by CCD camera, (b) Imaging result by OFR method : 940 - 1080 Hz

Stone・・As shown in Fig.14(b), a stone is a one of the difficult target for SLDV. There are many noises, because stone's response frequency range is over 1kHz. But using the OFR method, we can find the stone's response at its buried position.

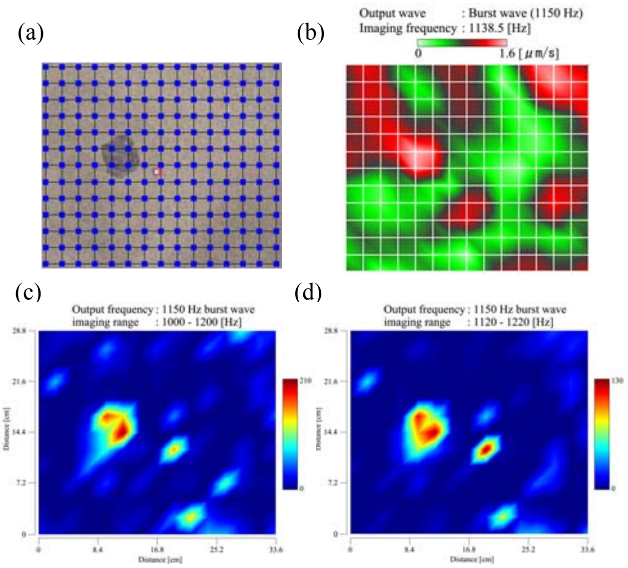

Figure 14. A stone, 1150 Hz burst wave results.(a) Buried position by CCD camera, (b) Imaging result of SLDV, imaging frequency : 1138.5 Hz, (c) Imaging result by OFR method : 1000 - 1200 Hz, (d) Imaging result by OFR method : 1120 - 1220 Hz

CONCLUSION

We confirmed the response range of the frequency of each buried objects and the effectiveness of our proposed OFR method. From the experimental result, it was possible to distinguish the buried objects by using the brightness image of the frequency response, and it was possible to make a clear image by using OFR method. It is thought that the difference of the frequency response range of each buried objects are affected by the resonance frequency. As a future task, the response range of the frequency of other media such as woods, metals and concrete and so on will be confirmed. Besides, based on these data, a new method of identifying buried objects will be developed.

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