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Optimum Frequency Range Method for Non Contact Acoustic Imaging in Extremely Shallow Underground
極浅層地中における非接触音響探査法用の最適周波数帯法

Tsuneyoshi Sugimoto[1†] and Touma Abe[2]
([1]Toin Univ. of Yokohama, [2]IHI Inspection & Instrumentation Co.,Ltd.)
杉本　恒美 [1‡]，阿部　冬真 [2] ([1] 桐蔭横浜大 工; [2]IHI 検査計測㈱)

1. 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.

2. Non contact acoustic imaging method

The fundamental concept of the non contact acoustic imaging method using the SLDV (Polytec Corp., PSV400 - H4) 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]

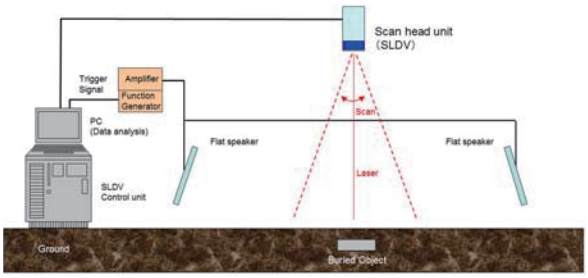

Fig. 1 Fundamental concept of exploration method.

3.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). A hollow plastic container (11 × 11 × 6 cm^3, 80g) 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)-(c)**. 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).

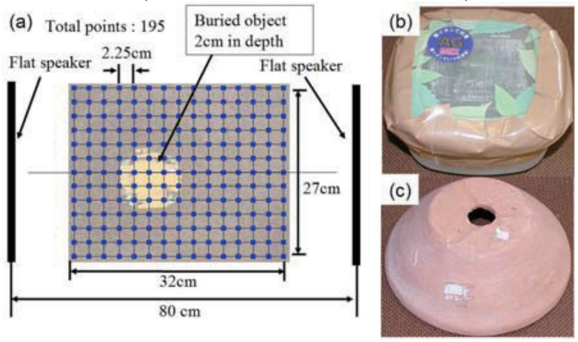

Fig.2 Experimental setup and buried objects.
(a) scan area size, (b) Plastic container,
(c) Unglazed pot

4. Optimum frequency range method

4-1 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 one by this calculation. The vibration velocity is standardized by the following equation.

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

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).

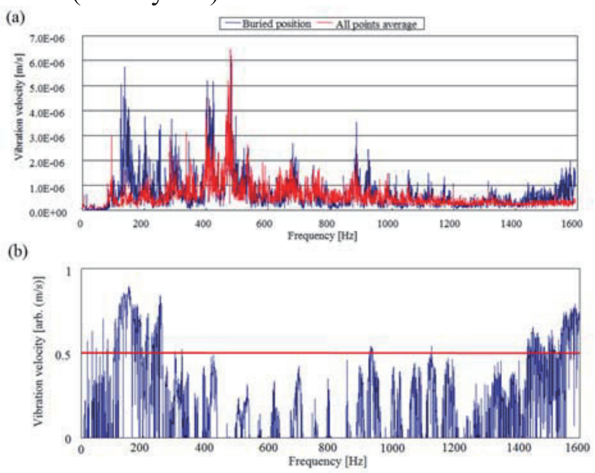

Fig.3 An example of vibration velocity vs. frequency (a) Comparison between the buried position (blue line) and all points average (red line), (b) Standardization result. Red line shows the threshold value for brightness imaging and OFR method.

4-2 Imaging by each frequency range

Using *D(x,y,ω)*, the candidates of the response frequency range 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.

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

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.

4-3 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）.

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

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.

4-4 Brightness image and OFR image

The brightness imaging results after standardization of each buried objects are shown in **Fig. 4(a)**. The response ranges of the frequency of the hollow plastic container and the unglazed pot are shown at 150 Hz and 1000 Hz. Each OFR images are shown in Fig.4(b)-(c).

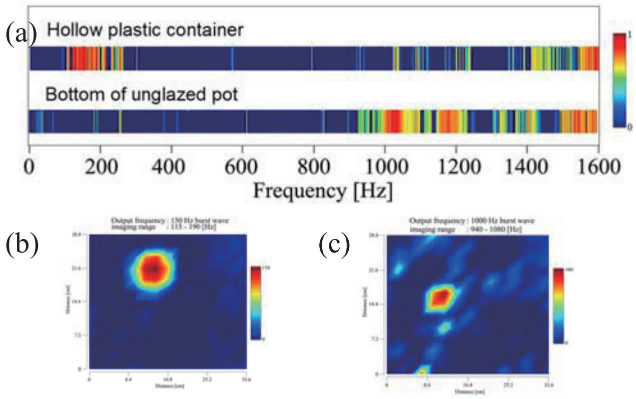

Fig.4 (a)Example of brightness images, (b)OFR image (hollow plastic container,115-190 Hz) and (c)OFR image(unglazed pot, 940-1080 Hz)

5. Conclusion

We confirmed the response range of the frequency of each buried objects and the effectiveness of the 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.

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