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Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 189-190
18-20 November, 2009

Imaging of Acoustic Scattering Object Using Time Reversal Wave Interpolated Between Microphones
マイク間で補間を行う時間反転波による音響散乱体のイメージング

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1. Introduction

In recent times, researches have been conducted on the application of time reversal waves, which are also known as phase conjugate waves[1-2] and used for imaging a reflective target.[3] One of the advantages of this method is that it has no restriction in the number of reflective targets to identify because it is essentially imaging an acoustic field. However, if the number of microphones is small, the convergence of the time reversal wave has been incomplete and an acoustic field has not been reconstructed well in conventional means.[4-5] Therefore we propose a solution of this problem using time reversal waves that are more precisely generated with the help of interpolation between microphones.

In this paper, power distribution due to acoustic scattering object (ASO) is imaged. Transmission-line matrix (TLM) method is employed for simulating time reversal waves.[6]

2. Principle of imaging acoustic scattering object

2.1 Imaging using time reversal waves

Waves are propagated in sound fields when there is no scattering and one ASO. They are also acquired at boundaries. Cross-correlation functions of these scattered waves and input wave are used for imaging. To image acoustic scattering, pulsed signal is ideal in theory. However, pulsed signal is hard to generate using an ordinary transducer. Therefore, considering the actual situation, a chirp signal is used instead of a pulsed signal for the input wave. It is converted into a pulsed signal in calculation by employing cross power spectrum phase (CSP)[7] analysis of the acquired wave in each microphone and an input wave. A difference is generated by subtracting one CSP waveform from another one. ASO is imaged using time reversal waves made of difference waveforms. The difference waves converge toward the ASO in the simulation so that the sound field is reconstructed and the ASO is imaged.

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2.2 Interpolation Between Microphones

The proposed method uses time reversal waves interpolated between microphones. The interpolated waves are generated with CSP waveforms of nearby microphones. First of all, arrival times of CSP waveforms are detected, and the arrival times corresponding to the locations between microphones are calculated with spline interpolation. Next, neighbor CSP waveforms to be interpolated are shifted by the calculated time, and the shifted CSP waveforms are added with weighting corresponding to the location of interpolation. The formula of interpolation is expressed as,

$$f_{n+l/d}(t) = \frac{d-l}{d} f_n(t+T_n) + \frac{l}{d} f_{n+1}(t-T_{n+1}), \qquad (1)$$

where $f_{n+l/d}(t)$ is the interpolated signal, l is the location of the interpolated points between neighbors, d is the distance between microphones, f_n is the signal of n-th microphone and T_n is the calculated time.

3. Simulation

3.1 Sound fields to be imaged

Figure 1 shows sound fields to be imaged. The size of area is 2 m×2 m. Sound sources are located at four corners of the area. ASO is located at (x, y) = (0.5, 1) (m) or (0.5, 1.3) (m) respectively. Diameter of each ASO is 0.2 m.

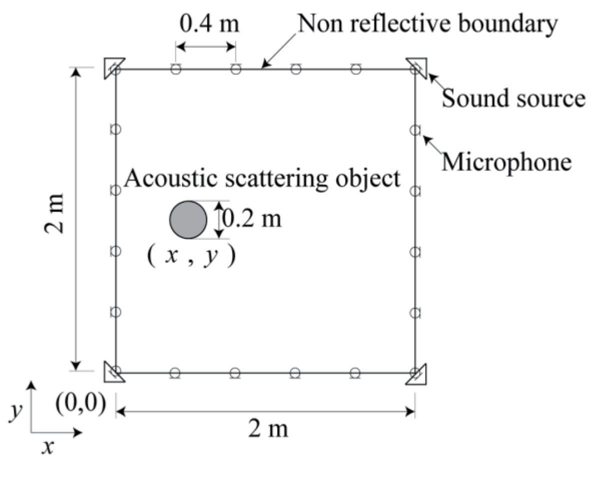

Fig. 1 Geometry for acoustic scattering object imaging

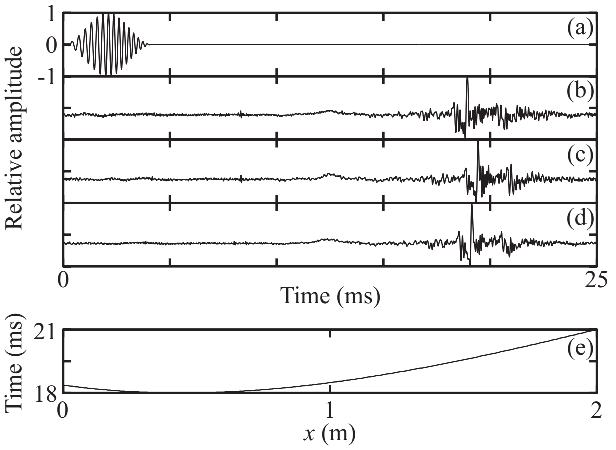

Fig. 2 Simulation result of waveform with acoustic scattering object at (0.5, 1). (a): Input waveform; (b): CSP waveform at (0.8, 2) (m); (c): CSP waveform at (1.2, 2) (m); (d): interpolated waveform at (1, 2) (m) (e): Spline interpolation of (0.01, 2) (m) to (2, 2) (m)

3.2 Simulation result

Figure 2 shows waveforms in the simulation. The input waveform is a chirp signal swept from 2 to 4 kHz, which is shown in Fig. 2(a). The waveforms acquired at two different locations on a boundary are shown in Fig. 2(b) and 2(c). Figure 2(d) shows an interpolated waveform at (1, 2) (m), which is generated from the above two waveforms. Figure 2(e) shows an arrival time curve calculated by spline interpolation. The time reversal waves of all the points on boundaries are generated with help of interpolation. All the points on boundaries are equivalent to the microphones. ASO can be imaged by this method, even though the number of microphones is small.

Figure 3 shows power distributions obtained in the simulation. In the case of a small number of microphones, only the position of ASO can be identified as shown in Fig. 3(a) and (d). These power distributions have radial patterns from each side. This cause is performing backward propagation only from five points of microphones on one side. In the interpolated case, the power distribution gets closer to that of large number of microphones as shown in Figs. 3(b), (c), (e) and (f). Compared with the former case, the backward propagation from the whole boundary with interpolation has an increased power at the time of convergence on the surface of an ASO. Therefore, the surface of the ASO is identified more clearly compared with the power distribution without interpolation. In addition, as for power being concentrated in the center of the ASO, the rippled distribution is observed at the convergence position after the convergence at the surface.

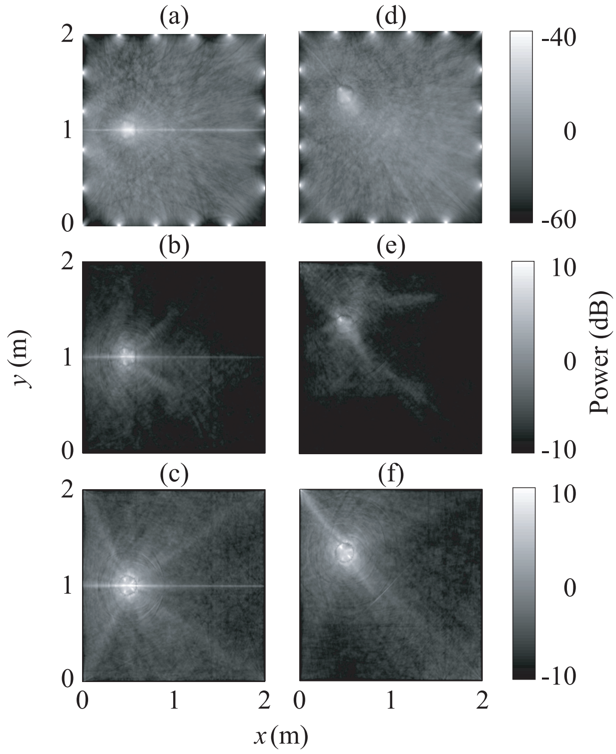

Fig. 3 Simulation result of power distribution. (a) and (d): 5 microphones on one side. (b) and (e): Interpolated distribution. (c) and (f): 300 microphones on one side. (a), (b) and (c): Acoustic scattering object at (0.5, 1) (m). (d), (e) and (f): Acoustic scattering object at (0.5, 1.3) (m).

4. Conclusions

In this study, we propose the method using interpolation between microphones for generating time reversal waves. Even though the number of microphones decreases, the power distribution getting closer to that large number of microphones case by the time reversal waves with help of interpolation.

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