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EXPERIMENTAL COMPARISONS OF SOUND VISUALIZATION METHODS FOR MOVING NOISE SOURCES

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1. INTRODUCTION

There has been a great attention to visualize not only stationary but non-stationary sound field, for example one formed by moving source. In the case of stationary sound field, various approach has been made to obtain the spatial information. Intensity method, acoustic holographic reconstruction, source identification using line array are three of these. When the source is moving, stationarity assumption no longer holds, which impulses one to apply new technique rather than conventional method. In this paper, two methods to visualize sound field formed by moving source using line array are described - which are planar acoustic holographic reconstruction and spherical beamforming. Experiments are performed with monopole-like moving source, a car and a motorcycle and the results using aforementioned methods are compared.

2. METHODS OF VISUALIZATION

Planar Acoustic Holography

It is well known that the planar acoustic holography can reconstruct the whole acoustic properties in space if the hologram is successfully obtained. However, it is not easy to measure the hologram of moving noise sources by the conventional measuring schemes[1]. In this article, we introduce a technique to get the hologram of moving noise sources with a fixed line array[2]. The basic idea of this method is that the temporal pressure signals which are measured on a fixed array are directly related with the spatial pressure distribution - hologram - when the sources are moving. That is, the temporal signals include the information of the spatial loci of moving sources as well as their frequencies. Suppose that the noise sources are moving with a constant speed of u and the frequency of f_0 along the x-axis, and the vertical array is fixed at x=0 on the hologram plane. Then the pressure signal, $p_m(t)$ at the microphone ($y = y_m$) can be expressed by the pressure $p(x_h, y_h, t)$ in the hologram coordinate, (x_h, y_h), which is moving identically with the sources;

$$p_m(t) = p(ut, y_m, t)$$

and its Fourier transform is related as

$$P_m(f) = \frac{1}{u}\tilde{P}\left(\frac{2\pi(f_0 - f)}{u}, y_h\right), \quad \tilde{P}(k_x, y_h) = \int_{-\infty}^{\infty} P(x_h, y_h) e^{-jk_x x_h} dx_h$$

where $$p(x_h, y_h, t) = \mathrm{Re}\{P(x_h, y_h) e^{-j2\pi f_0 t}\}$$

Using the above relations, one can obtain the hologram $P(x_h, y_h)$ from the measured pressure $p_m(t)$.

Spherical Beamforming for Moving Source

Conventional spherical beamforming method[3-4] is suitable for source localization in the nearfield. This method must be modified so that it can express the sound field generated by moving noise. This can be simply accomplished by introducing the weighting vector as

$$w_m(t) = \frac{1}{\sqrt{M}} e^{-j2\pi f(t) r_m(t)/c}$$

where M is number of microphone, r_m, the distance between the assumed source and m-th microphone and c, speed of wave. The other processing algorithm is the same as that of conventional one.

3. EXPERIMENTAL RESULTS

The experiment was done by using a vertical line array of 16 microphones and a horizontal array of 15 microphones as shown in Fig. 1. (The central microphone is shared by each array). The microphone spacing is 10 cm so that the visualization processing can be possible in the frequency range up to 1 kHz at least. The aperture size is 1.5 m, which covers up the height of moving sources. The horizontal array is only used in the spherical beamforming method to increase the horizontal resolution. To get speed of moving sources and the associated position with respect to time, two photoelectric sensors are used. At the first experiment, a speaker which generates sound with 700 Hz harmonic signal is attached on the side of moving vehicle and the previous methods are applied. Fig.

2.(a) and (b) show the reconstructed pressure magnitude and active intensity vectors on the surface of vehicle, and Fig. 2.(c) shows the beamforming power. The results point out the location of the prescribed source exactly, which assures one that the proposed methods are to be acceptable. Fig. 3. shows the results of a moving car at the frequency of 728 Hz. The dominant noise source is located at the part of front tire. Fig. 4. shows the map of noise source in a moving motorcycle at 807 Hz and the engine is main source.

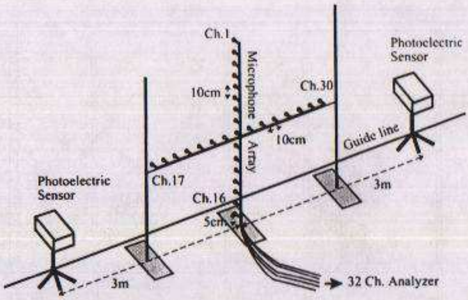

Fig. 1. Experimental setup - microphone line array and photoelectric sensors

4. CONCLUSIONS

We studied the planar acoustic holography and the spherical beamforming when the noise sources are moving with a constant speed. In the planar acoustic holography, the hologram could be obtained by transforming the temporal signals which were measured at the fixed array, to the spatial pressure distribution. However, since the spatial information as well as the associated frequency is included in the temporal signals, there exists a frequency criterion of the radiated sound i.e. the frequency difference of adjacent tonal component is large enough not to be overlapped by Doppler shift. Also the spherical beamforming was successfully accomplished by considering the time varying weighting vector. The methods were applied to the moving vehicles to reconstruct and visualize sound field and to identify noise sources.

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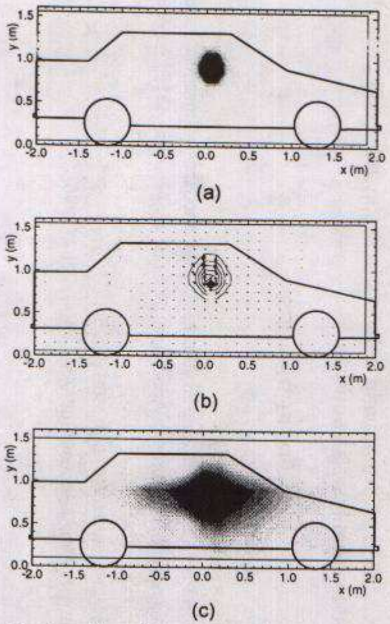

Fig. 2. Experimental result for a speaker at frequency of 700Hz (a) sound pressure (b) sound intensity (c) beamforming power

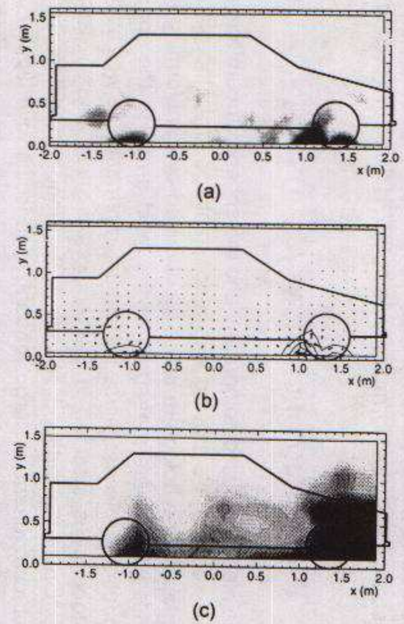

Fig. 3. Experimental result for moving car at frequency of 728Hz (a) sound pressure (b) sound intensity (c) beamforming power

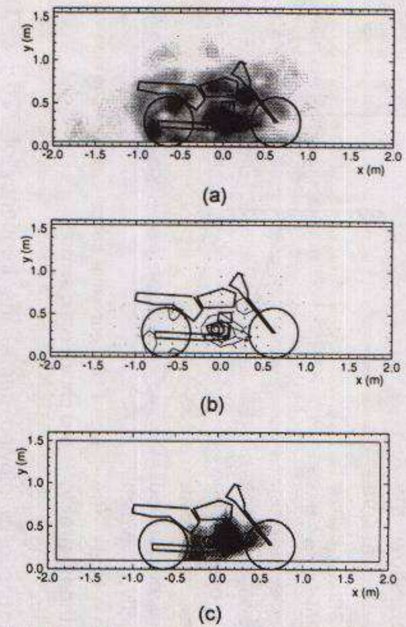

Fig. 4. Experimental result for moving motorcycle at frequency of 807 Hz (a) sound pressure (b) sound intensity (c) beamforming power