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Vector intensity measurement with a rigid spherical microphone array in a vehicle cabin

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Measurement results showing intensity vector reconstructions using a rigid spherical microphone array in a vehicle cabin are presented. The measurement equipment developed by Nittobo was used in previous demonstrations to visualize the acoustic field using a beamforming technique superimposed on a picture from an on-board camera. In the present study intensity reconstructions are shown and are successful in locating and quantifying sources, demonstrating the usefulness of this technique in an enclosed space like a vehicle cabin, aircraft cabin, small room, etc. This work was supported by the US Office of Naval Research and Nittobo Acoustic Engineering Co. Ltd.

1 Introduction

Spherical beamforming (Sp-BF) has been widely used in industrial applications [1, 2, 3, 4]. Especially, compared with planar BF, the merit of Sp-BF is its usefulness in an enclosed space, like vehicle cabin, airplane cabin, small rooms, etc, because the sound wave travelling from any direction around the sphere can be identified. In addition, the result is superimposed into the photo taken by on-board camera; rich acoustical information can be obtained with geometric information.

On the other hand, spherical nearfield acoustic holography (Sp-NAH) was developed recently [5], sound intensity flow was calculated successfully in an aircraft cabin with spherical microphone array without a shell. In this conference, a new formulation using a rigid spherical microphone array is presented [6].

In this paper, some applications of Sp-NAH in automotive field are presented. In addition, comparison Sp-NAH and Sp-BF in same measurement condition is performed and discussed.

2 Experimental study of Sp-NAH in a vehicle cabin

One of the most interesting enclosed space required quietness is vehicle cabin. There are various kinds of noise can be observed, like engine noise, gear whine noise from transmission, road noise from tire, wind noise, squeak and rattle, and so on. The frequency range to be interested is wide. For example, the booming noise generated by engine vibration and transmitted through body structure is observed from 20 to 200 [Hz] approximately. On the other hand, squeak and rattle can be found in higher frequency, from 500 to 5000 [Hz] approximately, but the power of squeak and rattle is very small and easy to be masked by other noises.

From another point of view, due to its small volume, the effect of eigenmode (standing wave) of vehicle cabin becomes dominant at low frequency. In such condition, sound field is quite different from free field. For such field, application of Sp-BF is suspicious, because beamfoming uses a kind of parametric modeling of sound field; its formulation is assumed sound propagation in free field. However, it is not assumed free field condition in Sp-NAH formulation. In this meaning, useful acoustical information in enclosed space is expected to obtain with Sp-NAH, especially in low frequency.

In this paper, an experimental study in hemi-anechoic chamber focused on engine noise is introduced. A commercial vehicle was put on a roller of chassis dynamometer with acceleration. The roller surface is covered with slip resistant material but not rough to generate significant road noise. The gear was selected second speed and revolution of the engine was kept 3000 [rpm] approximately by a driver. The rigid spherical microphone array was set at the passenger seat (left seat), as Fig. 2. Radius of spherical microphone array is 0.13 [m] and the number of microphone is thirty-one. In addition, twelve on-board cameras are equipped on the surface, and they were used to visualize Sp-BF results.

To obtain the coherent component related to the engine noise and vibration, an accelerometer was placed on the vehicle frame connected with engine mount directly.

,Fig.1 Vehicle in hemi-anechoic chamber

Fig.2 Rigid spherical microphone array in a vehicle

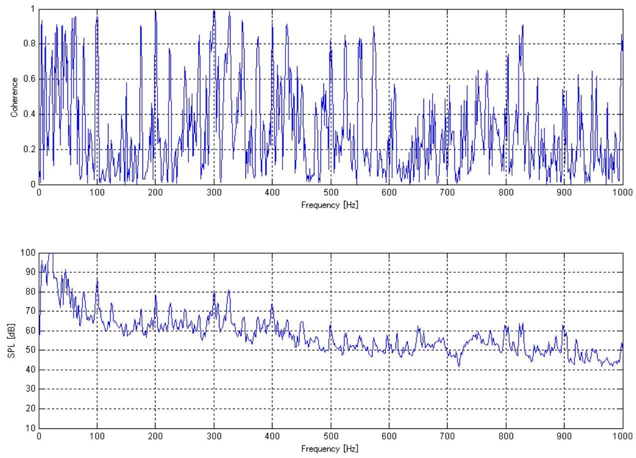
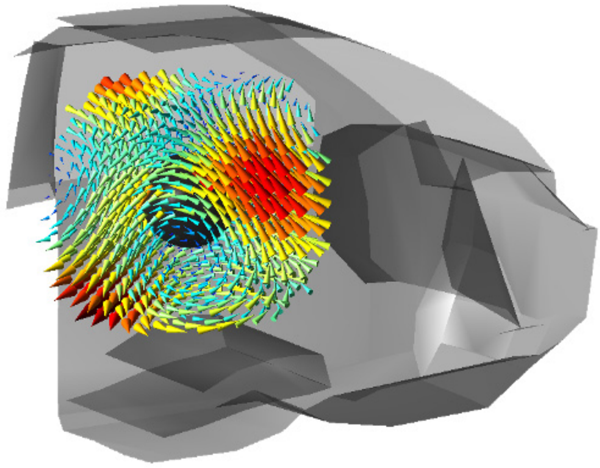
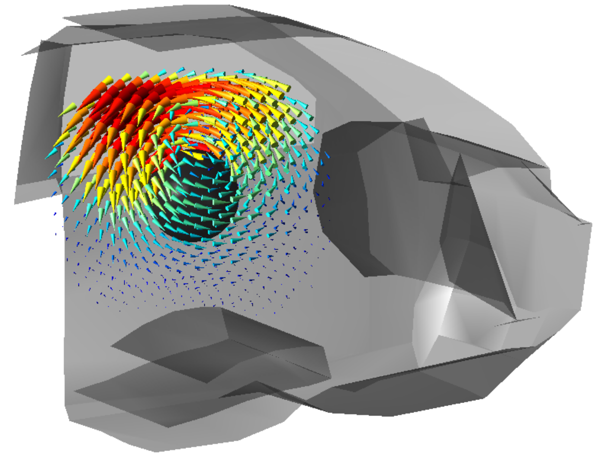


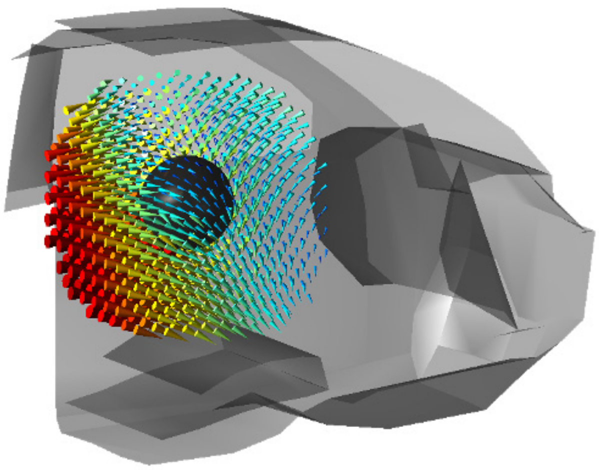
Fig.3 Coherence function between reference accelerometer and array microphone (above), SPL at array microphone (below)

Fig. 3 shows the coherence function between the signals at reference accelerometer and array microphone, and observed sound pressure level (SPL) at array microphone. Some components indicating peak related to the engine revolutions were picked up and analyzed to visualize sound intensity vector with Sp-NAH.

The visualized sound intensity are shown in Fig. 4, they are the result of 105 [Hz], 246 [Hz], 305 [Hz] and 398 [Hz] respectively. The result of 105 [Hz], which is the 1st order component of engine revolution, shows the acoustical energy flow from backward to the windshield, even if the engine is located in front. At 398 [Hz], the sound intensity is travelling along the ceiling.







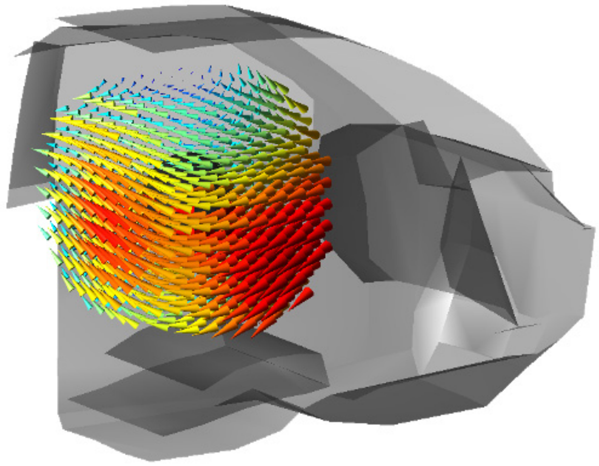


Fig.4 Sound intensity in a vehicle cabin
(from top, 105Hz, 246Hz, 305Hz and 398Hz respectively)

3 Comparison between spherical NAH and spherical BF

Fig. 5 and Fig. 6 show examples of analyzed result for same phenomenon with Sp-NAH and Sp-BF.
Fig. 5 shows the result at 199 [Hz], both result show the same noise source around windshield. On the other hand, Fig. 6 shows the result at 305 [Hz], sound intensity flow pattern is very complicated due to the standing wave mode of vehicle cabin. However, from the result of Sp-BF, it is difficult to imagine such phenomenon. This result shows that Sp-BF can provide us correct information only if the sound field is regarded as “almost” free field.
With Sp-BF, it is easy to understand the primary source location on the picture. The BF calculation is looking “far” field, and the output is a map shown “distribution of directive sound pressure level”. Generally, BF uses a parametric modeling of sound field, and the purpose of BF calculation is not aimed to obtain correct sound pressure or particle velocity at a point in the sound field, i.e., BF calculation is a kind of approximation to describe such sound field. With such approximation, Sp-BF can describe the sound field in “two-dimensional” way, i.e., the analyzed result is corresponding to θ and φ, not to r, in spherical coordinates. For this reason, it is easy to superimpose the results into the picture taken from surface of the sphere.

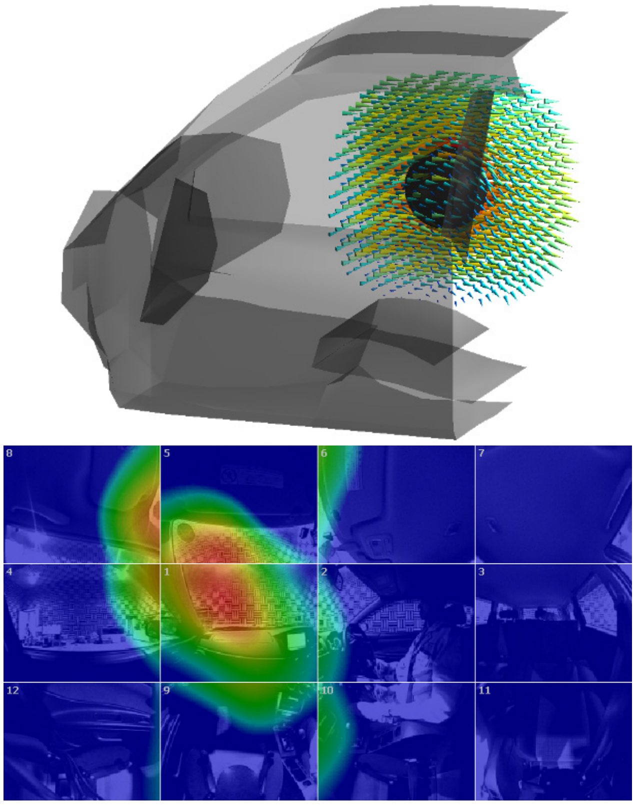


Fig.5 Comparison between Sp-NAH and Sp-BF (199 [Hz])

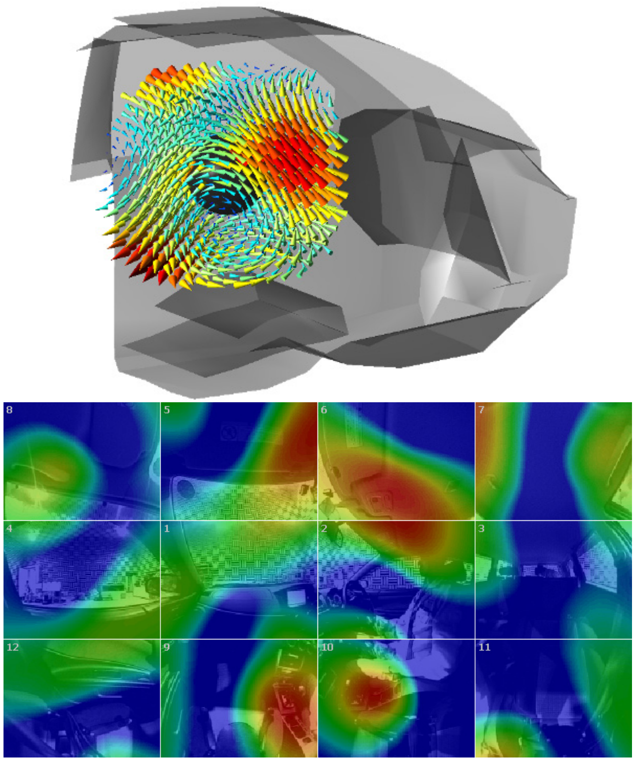


Fig.6 Comparison between Sp-NAH and Sp-BF (305[Hz])

On the other hand, the Sp-NAH uses much exact and general formulation of the sound field around the sphere, so both sound pressure and particle velocity close to the sphere surface can be calculated. In this meaning, Sp-NAH can describe the sound field in " three dimensional" way, i.e., the result is corresponding to θ, φ and r in spherical coordinates. However, it is difficult to display such three dimensional sound field information on the picture, because the ordinal picture includes two-dimensional geometric information only. To visualize a three-dimensional information into a picture, another way of expression should be considered.

4 Conclusion

An application of Sp-NAH to automotive noise problem is presented and discussed. With Sp-NAH, useful information can be obtained like acoustic intensity around the sphere. One of the greatest advantages of Sp-NAH is that such volumetric sound intensity flow around the sphere can be estimated from single measurement. It becomes easier to understand what is occurring in an enclosed space. Compared with Sp-BF, information obtained by Sp-NAH is more true to wave equation, but region for calculation is limited close to the sphere surface. However, with Sp-NAH, accurate sound field information can be obtained even if the sound field cannot be treated as free field. Compared with Sp-BF, this method is applicable for low frequency noise problem in small and enclosed space.
On the other hand, since the microphone array on a hard sphere is used, the sensor itself may affect to sound field characteristics. Such "negative" effect like multiple reflections (or scattering) between vibrating boundary and hard sphere should be observed in high frequency, where the size of hard sphere is relatively large compared with wavelength. Sp-NAH can be good enough to explain low frequency phenomena, like booming in a vehicle.

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