SOURCE IDENTIFICATION INSIDE CABIN USING INVERSE METHODS

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ABSTRACT

The presented sound source localization technique is based on the analysis of microphones array measurements. Here, the microphone array is a rigid sphere, which is well adapted to inside cabin acoustic fields (eg. vehicle, industry room…). Calculation points are located on a three dimensional mesh surrounding the measurement array. The method, which extends beamforming's algorithm capabilities, consists in reconstructing an equivalent source power distribution using a Green's function transfer matrix and an adapted inversion procedure.

Generally speaking, propagation transfer function inversion is an important point when using inverse methods to identify sound sources. It is, for example, responsible for the efficiency of the method and must be adapted to the measured acoustic field. This paper compares two inversion methods, the first being based on a singular value decomposition operation and the second on an iterative algorithm.

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1 INTRODUCTION

Noise mapping in free field using planar microphones antenna have been widely studied[1] and used[2] in a number of industrial applications until now. In the case of a three-dimensional and inside cabin localization procedure, classical array processing and microphone antenna geometries have to be re-adapted to face new problems, such as separating the incident and scattered fields or dealing with a complex calculation mesh grid.

Acoustical mapping of an entire vehicle interior can be achieved using a rigid solid sphere with surface mounted microphones. It has been shown that such antenna is well adapted to interior noise source localization[3], through its masquing effect for diameter opposed microphones, which improves the forward and backward waves separation.

Localization techniques can be grouped in 3 categories: Nearfield Acoustical Holography[1] (NAH) methods, beamforming based methods, and inverse methods. NAH's main advantage lies in its good low frequency resolution but requires measurements to be done in the nearfield of the sources. Furthermore, in the spherical case, NAH calculation can only be achieved on a spherical surface. On the contrary, beamforming processing is more flexible in that the associated microphones array and calculation mesh are not constrained. Furthermore, beamforming's main limitations lying on its poor low frequency resolution can be surmounted by the use of recently developed inverse methods. Two of them will be compared in this paper, the first being based on a deconvolution of the previously calculated beamforming pattern through an iterative calculation processing, the second consisting in a Tikhonov-based inversion of the transfer matrix built directly with the microphones'positions. A brief overview of their underlying theory will be presented in the first paragraph. The second paragraph will be dedicated to the comparison on chosen simulation cases.

2 INVERSE PROBLEM FORMULATION

The point of the problem is to find a solution to a system of equation modelled by

$$p = Hq \qquad 2.1$$

where p (m x 1) are the m outputs, q (n x 1) are the n inputs, and H (m x n) the matrix of acoustic transfer functions between the inputs and the outputs.

In both approaches described in the following paragraphs, q stands for the volumetric velocities of the equivalent source distribution we want to compute. The calculation of the transfer function H differs in each method in that p successively stands for the beamformed acoustic pressures or the microphones pressure. In each case, transfer functions to the rigid sphere take the diffraction around its solid body into account. So, the expression of the pressure in the direction θ from the radiation on a "a" radius solid sphere surface is given for a "r" microphone-source distance greater than the sphere radius for "ω" frequency by[5]:

$$p(r,a,\omega,\theta,t) = \frac{i\rho c Q}{4\pi a^2}\Psi e^{-i\omega t} \qquad 2.2$$

where Ψ represents the spherical harmonics expansion for r>a.

3 ITERATIVE DECONVOLUTION APPROACH

3.1 Iterative deconvolution approach

The classical delay and sum beamforming formulation for a set of N microphones positioned at $\vec{x}_n$ gives the focused pressure at a point $\vec{x}_k$ by

$$P_k\left(\vec{x}_f, t\right) = \sum_{j=1}^{N} w_j^k p_j\left(t + \frac{r_{kj}}{c}\right) \qquad 3.1$$

where $w_j^{(k)}$ is a given weighting factor and r_{kj} is the distance between the focus point $\vec{x}_k$ and the microphone M_j.

The Equivalent Source Method (ESM) which is also referred to as Source Density Modelization (SDM)[5,6] considers a discrete omnidirectional source distribution with spherical radiation characteristics. Furthermore, we assume an uncorrelated source distribution, so that its spectral cross power density $\Psi(q_n, q_{n'})$ can be reduced to its diagonal terms Ψ_n. This auto-power source density can now be related to the focused pressure P_k using a transfer function matrix $H_{k,n}$ by the matrix linear system

$$P_k = \sum_n H_{k,n} \Psi_n \qquad 3.2$$

where $H_{k,n}$ includes the Green's propagation function as well as the beamforming focusing function between the sources and the beamformed focus points. Thus, $H_{k,n}$ contains the beamformed backpropagation signature of the array geometry, and solving eq. (3.2) leads to an array signature free source power distribution Ψ_n.

Eq. (3.2) can be solved through an iterative Non-negative Least square algorithm with the initial source distribution provided by the beamforming pattern. Then, iteration formula is given by

$$\Psi_n = \Psi_{n-1} + \alpha(P_0 - H\Psi_{n-1}) \qquad 3.3$$

where α is an iteration velocity parameter and P_0 the original beamformed pressure pattern.

4 IFRF METHOD WITH TIKHONOV REGULARIZATION

4.1 Theory overview[6]

Here, the vector p from equation 2.1 represents the acoustic pressures measured by the microphones. Thus the number of sources (n) is superior to the measurement points (m) if one wishes to get a fine spatial discretization of the cavity. As a consequence, the number of rows of H is superior to the number of its columns, leading to an under-determined case which imposes a regularization while inverting H[5,8].

First, H can be decomposed into its singular value form and the system would then be

$$p = U_{[m,m]} S_{[m,m]} V^{*}_{[s,m]} q \qquad 4.1$$

The inversion of the very small singular values (often measurement noise) leads to an over-amplification which can be avoided with the use of the Tikhonov regularization.

The ist regularized solution is now given by

$$q_i = V_{[s,m]} diag\left(\left[S + \beta_i / S\right]^{-1}_{[m,m]}\right) U_{[m,m]} p_{[m,1]} \qquad 4.2$$

where βi is the i[st] regularization parameter. The optimal regularization parameter is chosen according to references [5,8] with GCV (Generalized Cross Validation) method in low frequency and L-curve in higher frequency.

5 COMPARISON OF THE METHODS

5.1 Measurement array

As inverse methods and spherical beamforming don't impose the use of regular microphone arrays, a pseudo-random distribution is used, allowing to get a better side lobe behaviour for the same mean microphone spacing. The solid sphere used in simulation results comparison and experiments results has a 15 cm radius and 36 microphones pseudo-randomly distributed around its circumference, keeping half sphere symmetry.

5.2 Simulation results comparison

Simulation is done with two equivalent correlated white noise sources which are located one meter away from the sphere centre and under an angle of 90° from each other. The 3D calculation grid is a 2m square cube, with each source at the centre of one face. Figure 1 shows the localization results for two phased correlated sources, and compares the results for the spherical beamforming processing, the iterative inverse method and the IFRF Tikhonov based inverse method.

Beamforming processing's resolution is proportional to the wavelength, so it is unable to separate the two sources beyond the 1kHz third octave band. Iterative deconvolution process and IFRF Tikhonov based method have frequency independent resolutions. The iterative process has the best resolution from 1kHz.

IFRF Tikhonov based method separates the sources at the 400 Hz third octave band keeping the precise localization of the two sources. On the contrary, at low frequencies, the iterative deconvolution method fails to separate the two sources which tend to regroup themselves at their centre. This difference in their behaviour with correlated monopoles that are in phase can be explained by the fact that the iterative deconvolution method works with a quadratic density source calculation grid in its input and a quadratic beamformed pressure map in its output, so that the phase relations between the two sources are not taken into account (Random Phase Approximation[6]) and finally the deconvolution process is unsuccessfull. One can notice that the spherical beamforming sources' deviation to the centre of the sources' real position is the same.

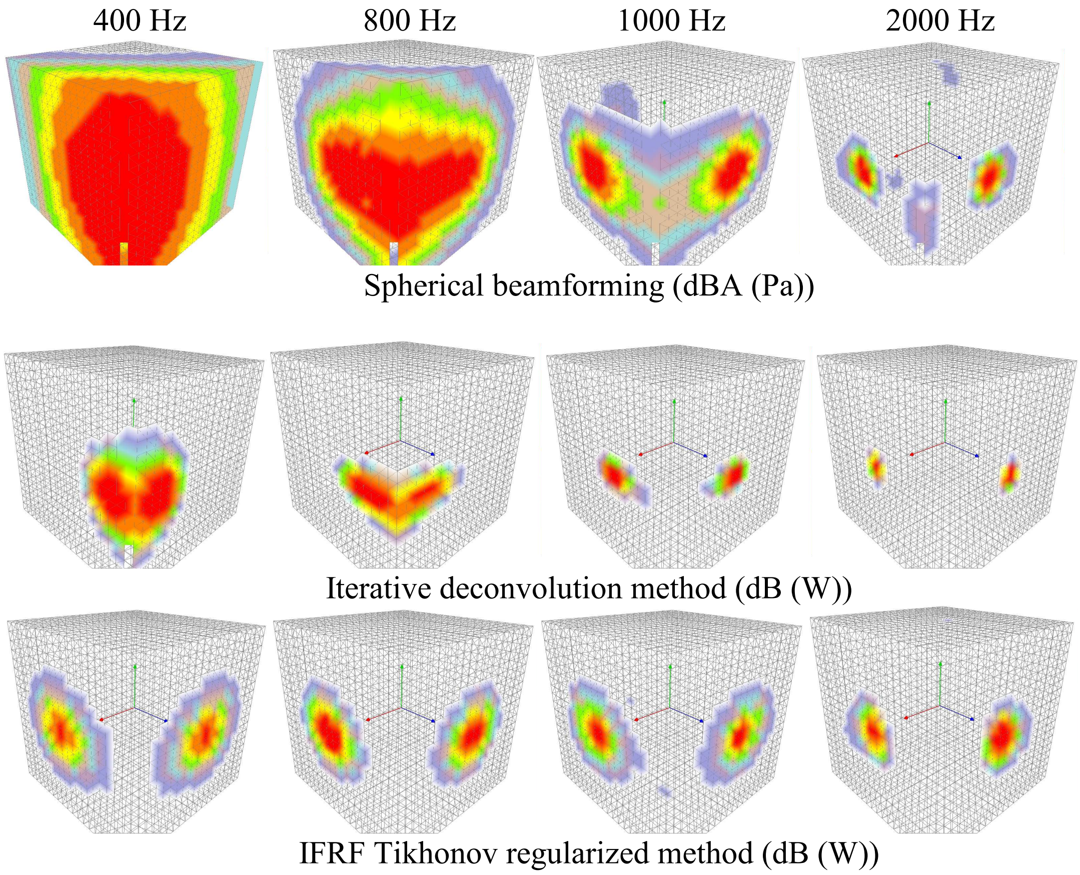

Fig. 1. Localization of two simulated monopoles in phase, located at 1m from the centre of the measurement sphere.

Figure 2 shows the localization results for two correlated sources in opposite phase, and compares the results for the different localization methods. As for the previous simulation case (in phase correlated sources), the best resolution is obtained for the iterative deconvolution process. On the contrary, a source position deviation appears beyond 800Hz for the spherical beamforming and the iterative deconvolution process putting away the two sources from their real positions. This deviation is not observed with the IFRF Tikhonov based method where the sources are well positioned on all the calculated frequencies.

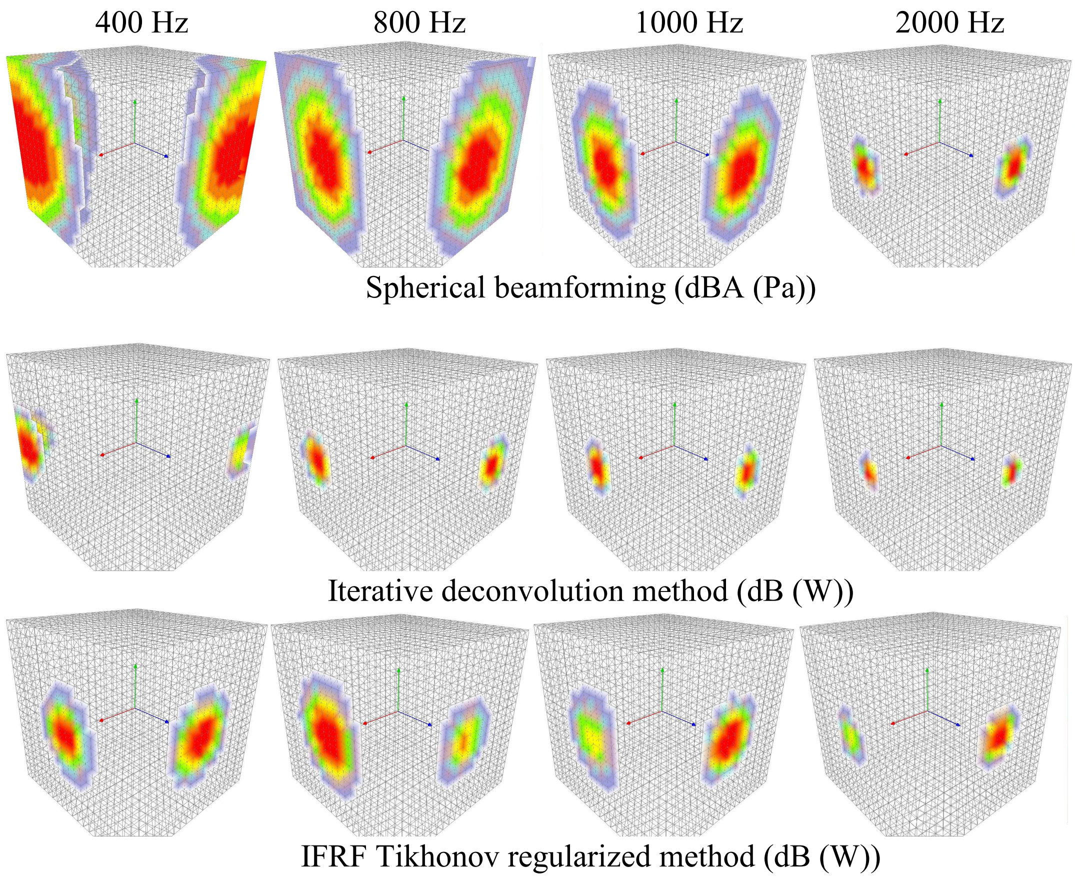

Fig. 2. Localization of two simulated monopoles in opposite phase, located at 1m from the centre of the measurement sphere.

5.3 Inside vehicle experiments

Fig.3 presents a real case localization procedure of a seal default at the corner of the front passenger door. At 1 KHz, as observed on the simulation results, IFRF method and spherical beamforming lead to the same results and the iterative deconvolution method performs a better resolution, with a gain of approximately a factor of 2.

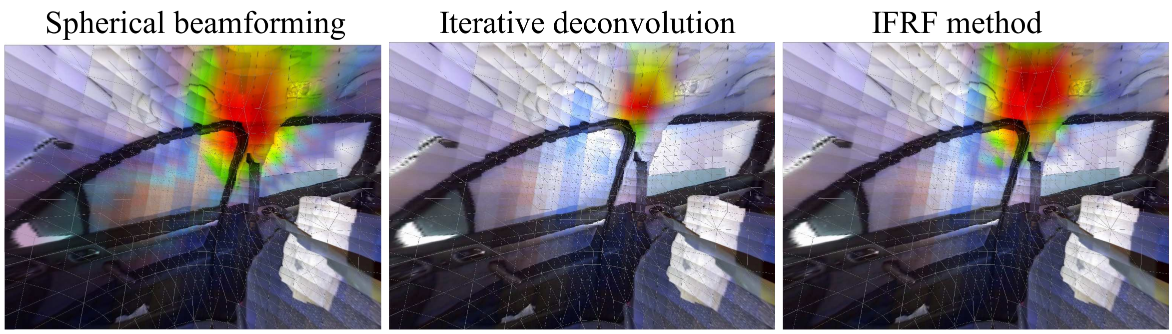

Fig. 3. Localization of a real aeraulic source at 1100 Hz with the spherical beamforming processing (left), the iterative deconvolution process (centre), and the IFRF method (right).

6 CONCLUSIONS

Two inverse methods, dedicated to the improvement of the localization procedure inside cabin with a rigid spherical microphone array were compared with two correlated simulated monopoles, and on a real case study. Both inverse methods lead to an enhanced resolution in low frequency and perform similar results to spherical beamforming at medium and high frequency. The better resolution, when it deals to the localization of only one source, is being reached with the iterative process. With two correlated sources, the IFRF Tikhonov based method is the most robust processing.

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