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Spherical Harmonics Decomposition in inverse acoustic methods involving spherical arrays

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ABSTRACT

Inverse methods for acoustic source mapping have gathered the attention of the beamforming community during the last years. Indeed, they provide higher accuracy in both source localization and strength estimation with respect to Conventional Beamforming (CB). One of the main drawbacks of the current formulations is the need of a regularization strategy for tackling the ill-posedness of the problem. Very often, Tikhonov regularization is exploited to face this issue, but different methods for estimating the regularization factor associated to the Tikhonov formulation may lead to different regularization levels and, therefore, to different results. This paper presents a way to face this problem when dealing with spherical arrays. The new approach proposed by the authors exploits Spherical Harmonics Decomposition (SHD) of complex pressure data at microphone locations. SHD performs a spatial filtering that reduces the effect of noise and causes an intrinsic stabilization of the numerical problem associated to the inverse problem formulation. When the source-receiver propagation model is appropriate to describe the acoustic environment in which the test takes place and noise is not spoiling excessively measurement data, the SHD approach is sufficient to obtain a regularized solution. If these conditions are not satisfied, SHD can be exploited as a pre-processing step in a twofold procedure also involving classical Tikhonov regularization. In this paper the SHD approach is tested in the *Generalized Inverse Beamforming* (GIBF) formulation. Classical Tikhonov approach, in which the regularization factor is estimated using the Generalized Cross-Validation (GCV), L-curve functions and Bayesian regularization, is presented as a way to enhance data processed by SHD. A sensitivity analysis of the approach to measurement noise and source-receiver relative positions is presented on simulated data. Results on experimental data are presented and discussed for both a simplified test case and an application to a real car cabin.

1. Introduction

Acoustic mapping in enclosed spaces is gaining importance in many sectors, but particularly in vehicle NVH (Noise and Vibration Harshness). The goal is to locate disturbing noise sources so to improve the cabin acoustic comfort. Microphone phased-array techniques are often used to face this problem. Interior noise source localization generally requires three-dimensional array design, even though some strategies can be adopted to exploit planar arrays [1]. The commonest three-dimensional solution relies on spherical arrays. Indeed, they are simple to assemble and they make it possible to use dedicated algorithms, like *Spherical Harmonics Beamforming* (SHB) [2,3], which are nowadays well established among the NVH community. Both transpar-

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ent or rigid scattering spheres are typically used. The latter are often preferred as microphones are flush-mounted on a rigid surface and amplitude and phase differences are enhanced by the surface itself. Over the last years, attention has been steered to inverse methods since they can provide a quantification of the strength of the noise sources, rather than just their location. As they can successfully deal with distributed sources, multipoles and coherent/incoherent sources, inverse methods are more common in the aeroacoustic community [4,5]. Among the different algorithms, the Generalized Inverse Beamforming (GIBF) approach [4] has gained particular relevance in the last years. GIBF models the source-receiver acoustic problem as a linear system in which the source-strength distribution and the pressure at the receiver location are linked by a transfer matrix. This matrix has to be inverted to solve the system. The model adopted in the GIBF formulation is ill-posed (the number of potential sources is higher than the number of microphones) and often ill-conditioned. A regularization strategy is therefore required. For example, Zavala et al. [5] suggest a different regularization strategy for GIBF with respect to the one proposed by Suzuki.

In this context, the final aim of the present paper is to discuss an approach, which is based on Spherical Harmonics Decomposition (SHD), that can be exploited to stabilize the numerical problem, especially in the low-to-mid frequency range, when GIBF is utilized to process spherical array pressure data. The SHD approach is well-known in the beamforming community. Rafaely [6] performed a comparison between Delay and Sum (DAS) and SHB. He showed that the performance of the two solutions differs mainly in the low frequency range, where the SHD-based processing, because of its intrinsic combined spatial filtering/data fitting action, makes it possible to have a constant directivity with no deteriorations. Instead Chu et al. [7] combined deconvolution methods with SHB. An interesting approach to improve the performance of spherical arrays at low frequency, where spheres of bigger diameter should theoretically be exploited, was proposed by Tiana-Roig et al. in Ref. [8]. They suggested to perform SHB on virtual pressure data calculated by acoustic holography from a physical hard spherical array, at a larger diameter with respect

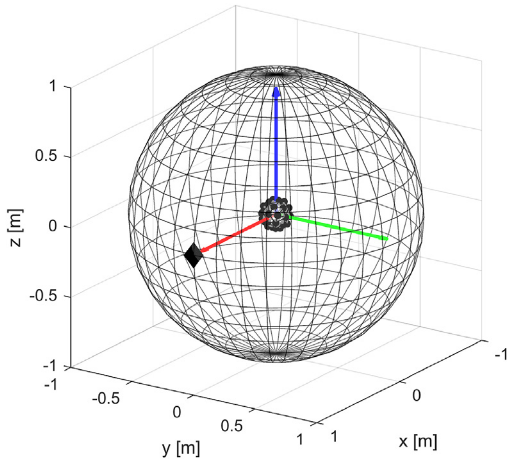

Fig. 1. Setup of simulated experiment.

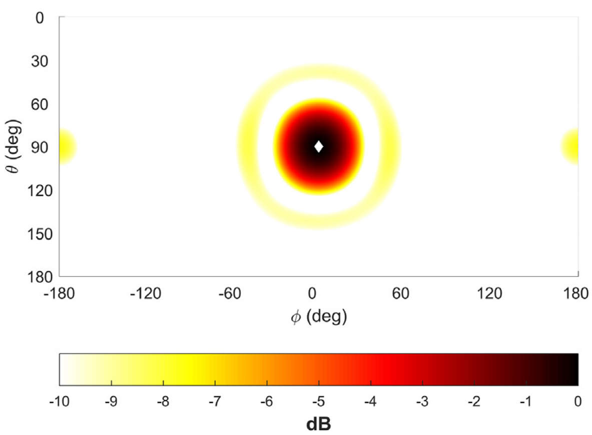

Fig. 2. Example 1 - GIBF on noise-free data: exact solution - $f = 1$ kHz, $ka = 1.83$, $dB_{reference} = 1\ m^3/s$.