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Localized Method of Fundamental Solutions for Acoustic Analysis Inside a Car Cavity with Sound-Absorbing Material

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Abstract. This paper documents the first attempt to apply a localized method of fundamental solutions (LMFS) to the acoustic analysis of car cavity containing sound-absorbing materials. The LMFS is a recently developed meshless approach with the merits of being mathematically simple, numerically accurate, and requiring less computer time and storage. Compared with the traditional method of fundamental solutions (MFS) with a full interpolation matrix, the LMFS can obtain a sparse banded linear algebraic system, and can circumvent the perplexing issue of fictitious boundary encountered in the MFS for complex solution domains. In the LMFS, only circular or spherical fictitious boundary is involved. Based on these advantages, the method can be regarded as a competitive alternative to the standard method, especially for high-dimensional and large-scale problems. Three benchmark numerical examples are provided to verify the effectiveness and performance of the present method for the solution of car cavity acoustic problems with impedance conditions.

AMS subject classifications: 65N80, 62P30, 35J05

Key words: Acoustic analysis, localized method of fundamental solutions, car cavity, sound-absorbing material.

1 Introduction

Acoustic analysis plays a significant role in many fields such as vehicle noise control [1, 2] and indoor sound insulation [3, 4]. In recent years, a large amount of research [5–8] has been devoted to the acoustic analysis and simulation in practical engineering and

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industry fields. In the numerical algorithms, the finite element method (FEM) [9, 10], finite difference method (FDM) [11] and boundary element method (BEM) [12] are the most common methods in the simulation and calculation of interior acoustics field. At present, the FEM and the BEM have been considered as powerful tools for numerical simulation of acoustic problems. However, these approaches are difficult to avoid the tasks of mesh generation and numerical integration, which is often very time-consuming and tedious, especially for high-dimensional and complex geometries.

Over the last few decades, many efforts have been made to develop new numerical schemes in order to reduce or completely avoid gridding as well as numerical integration. Various meshfree methods or meshless methods [13–17] have been presented and applied to the acoustic analysis. These methods can be roughly classified into two categories, namely, boundary-type methods and domain-type methods. The former mainly includes the method of fundamental solutions (MFS) [18–21], the boundary knot method (BKM) [22, 23], the singular boundary method (SBM) [24, 25] and so on. The latter includes the generalized finite difference method (GFDM) [26,27], the element-free Galerkin method (EFGM) [28, 29], the radial basis function collocation method (RBFCM) [30] and so on. For details on advance and application of meshless method, the readers can refer to [31–33] and references therein.

To overcome the bottleneck that the boundary-type method with global discretization is difficult to apply to large-scale problems, recently, the localized versions of the boundary-type meshless methods including the MFS, the BKM and the SBM have been proposed. Wang et al. [15, 16, 34, 35] presented the localized BKM (LBKM) for simulating convection-diffusion-reaction problem and acoustics problem. Liu and Fan et al. [36] developed the localized Trefftz method and applied it to numerical solutions of Laplace equation and biharmonic equation. Xi and Fu et al. [37] presented a localized collocation Trefftz method for heat conduction analysis in two kinds of heterogeneous materials (functionally graded materials and multi-medium materials) under temperature loading. Wang et al. proposed a localized SBM and a localized Chebyshev collocation method [38, 39]. Fan and Chen et al. [40] proposed the localized MFS (LMFS) for solving boundary value problems governed by Laplace equation and biharmonic equation. Very recently, Gu, Wang, Li et al. [41–45] applied the LMFS to the elastic wave, diffusion, inverse problem, heat conduction problem and so on. Qu et al. [46, 47] made a first attempt to employ the LMFS to simulate three-dimensional (3D) interior acoustic fields at low frequency as well as two-dimensional (2D) interior Helmholtz problems with high wave number. In their works, however, the closed space with a sound absorbing material has not been considered, which is a common issue in many applications. Moreover, the investigation of the LMFS in the acoustic analysis of car cavity with impedance condition has not been reported yet.

In this paper, the LMFS is firstly implemented to predict the sound field in a car cavity with impedance boundary conditions and medium-low frequencies. The LMFS is free from numerical integration and mesh generation. Only some regularly or irregularly distributed nodes are required both inside the physical domain and on its boundary.