Wave-Based Virtual Acoustics

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PhD thesis abstract

Research has shown that room acoustics has a major influence on the well-being, health and productivity of building users, e.g., in schools, hospitals and office buildings. Room acoustic simulations are a valuable tool for building designers to optimize the acoustic conditions of their designs prior to construction or renovation. The purpose of this PhD study is to contribute to the field of room acoustic simulations, with the aim of improving the simulation accuracy, efficiency and usability.

The numerous simulation methods that have been proposed in the literature are typically divided into *geometrical acoustics* methods or *wave-based* methods. Geometrical acoustics, based on a notion of rays in the high frequency limit, are generally computationally efficient, but the accuracy can be low, particularly in cases where wave phenomena such as diffraction and interference are prominent. In wave-based methods, the governing equations of wave motion in an enclosure are solved directly, yielding highly accurate schemes, but hampered by excessive computation times. In this study, a new type of time-domain wave-based simulation scheme is developed, based on cutting-edge numerical techniques: the *spectral element method* and the *discontinuous Galerkin finite element method*. These numerical methods possess the attractive qualities of high-order accuracy, geometric flexibility and suitability for parallel computing. It is shown how the proposed numerical scheme can simulate complex rooms with high accuracy and short computation times, thereby extending the usability of wave-based simulations far beyond the historically limited case of small rooms and very low frequencies.

The absorption properties of room surfaces are a major determinant of the acoustics of rooms. Previous research has indicated that a lack of accurate boundary modeling is a critical issue in room acoustic simulations. In this study, two methods for modeling the *extended-reaction* behavior of room surfaces in time-domain wave-based room acoustic simulations are proposed. It is shown that these methods significantly improve the accuracy of the simulations, as compared to the commonly used local-reaction model. A framework for carrying out uncertainty quantification due to boundary condition input data uncertainty is proposed and applied.

Another challenge with acoustics in building design is that non-experts such as architects, stakeholders and clients have a hard time relating to acoustics, it being an intangible and invisible phenomenon. *Auditory virtual reality* (AVR) can be a way to make acoustics more tangible, by coupling accurately simulated 3D sound with immersive visual models. However, this imposes additional challenges on the acoustic simulation algorithms. A method for generating an AVR experience based on accurate pre-computed room simulations is proposed. The method is analyzed with subjective tests and applied to real building design cases. Furthermore, on-going work on developing accurate real-time virtual acoustics schemes is presented, based on model order reduction techniques to accelerate the wave-based scheme further, and on the hybridization of wave-based and geometrical acoustics simulation schemes.

Keywords: *Wave-based room acoustic simulations, high-order finite element methods, extended-reaction boundary condition modeling, auditory virtual reality, model order reduction, high-performance computing.*