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Mesh-Free CAD-Based Isogeometric Vibro-Acoustic Analysis for Automotive NVH Applications

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The accurate prediction of vibro-acoustic behavior in complex engineering systems, particularly in the automotive NVH (Noise, Vibration, and Harshness) context, remains a challenging task due to the geometric complexity and the need for high-fidelity numerical models. Traditional finite element approaches require time-consuming mesh generation and often introduce geometric approximation errors when transitioning from CAD models to analysis-suitable discretizations.

In this work, a novel isogeometric analysis (IGA) framework is presented to perform vibro-acoustic simulations directly from CAD geometries, effectively bypassing the need for conventional meshing procedures. The proposed approach relies on an immersed methodology in which the acoustic cavity is reconstructed from the original CAD representation and embedded into a structured computational domain. Hierarchical B-Spline basis functions are employed to enable local refinement, maintain geometric exactness, and ensure high-order continuity, which is particularly beneficial for wave propagation problems.

The vibro-acoustic coupling is achieved through a consistent interaction between the acoustic domain and structural components modeled as shell elements, allowing for an accurate representation of fluid-structure interaction phenomena. This integrated framework supports efficient handling of complex geometries and provides numerical stability and accuracy compared to standard approaches.

The methodology is applied to an automotive case study, focusing on the vibro-acoustic response of a vehicle cabin derived directly from CAD data. Results demonstrate the capability of the proposed method to capture relevant acoustic modes and structural coupling effects while significantly reducing preprocessing effort. The approach shows strong potential for industrial NVH applications, where rapid design iterations and high geometric fidelity are essential.

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