PROPOSITION DE SUJET DE THÈSE

Intitulé : Isogeometric Discontinuous Galerkin approaches for vibration analysis of lattice structures for aerospace applications

Référence : **SNA-DTIS-2025-25**
(à rappeler dans toute correspondance)

Début de la thèse : 01/10/2025	**Date limite de candidature :** 01/06/2025

Mots clés

Lattice structures, Viscoelastic Material, Vibration Suppression, Isogeometric Analysis, Discontinuous Galerkin, Non-Linear Problem

Profil et compétences recherchées

Master 2 ou école d'ingénieur

Mathématiques appliquées, analyse numérique, simulation, informatique.

Présentation du projet doctoral, contexte et objectif

The development of additive manufacturing technologies has revolutionized the design of architectured metamaterials. These materials may play a transformative role in new generation space missions due to their unique properties. For instance, lattice structures possess a high strength to mass ratio and play a major role in the design of spacecraft and space habitats where both mass and volume constraints are critical. Furthermore, they can adapt their properties over time [1], and are responsive to change in temperature and radiation. They can therefore be tuned to maintain optimal performance, making them perfect candidates as thermal insulators [2] and radiation shields. Numerical methods are crucial in lattice structure design. Simulations are needed to model coupled and multiscale phenomena that may occur in these materials. Optimization algorithms may be used to explore the vast design space and perform inverse designs to obtain materials with desired properties. However these new possibilities come with additional difficulties as metamaterials exhibit intricate geometries and complex anisotropic material behavior. These numerical challenges require the development of newly established techniques, capable of capturing the geometric and the intricate structures of lattice materials.

In this thesis project, we aim to combine isogeometric finite element methods with discontinuous Galerkin methods for advanced numerical modeling of lattice structures. The employment of isogeometric analysis (IGA) is motivated by its ability to precisely fit curved geometries, like the ones found in lattices, i.e. networks of thin rods and shells [3,4]. These elements are challenging to simulate numerically as they utilize highly regular approximation bases that are not easy to construct. Even if IGA constructs high-regularity functions seamlessly by using splines inside an element, constructing an overall regular field over complicated geometries remains challenging due to the need for multiple patches [5,6]. Discontinuous Galerkin methods overcome these difficulties by incorporating higher regularity in a weak manner [7,8,9]. Furthermore, they hold the promise for better computational performance, because of the local nature of the matrices resulting from the finite element assembly. This is especially important when a full fine scale analysis of a lattice structure is required, as the computational cost of such a simulation is huge and efficient solvers need to be carefully designed (cf. [10] for a recent work on rapid static simulation of lattice structures).

In this thesis, the main focus will be on vibration analysis of structures, with vibration suppression applications in mind [11]. To this aim, efficient numerical strategies for the time integration of fine scale lattice structures need to be developed. For vibration suppression, the material needs to be viscoelastic. The simulation of these materials poses several challenges on the numerical side, as the construction of a parsimonious yet effective viscoelastic model is a delicate task. Furthermore, the modal analysis of these materials is non linear as their behavior depends on the frequency. Numerical algorithms for this problem are non-standard, like an Arnoldi non linear iterative eigensolver [12]. Other important extensions include the multiphysical modeling of piezoelectric material for active vibration control. This represents a challenge as in isogeometric analysis the control points underlying the finite element representation do not lie on the physical boundaries and immersed approaches may represent a possible solution [13].

Plan :

- Explore different discontinuous methods (HHO, DG, HDG) to obtain an efficient formulation for weak imposition of regularity in a multipatch isogeometric context. Numerical analyses of methods on simple examples, i.e. linear elastic static beams, plates (maybe shells) and linear elastic wave propagation.
- Development of efficient algorithmic solutions for time stepping and nonlinear modal analysis strategies for vibration of viscoelastic material.
- Code development in efficient programming language (Fortran, C++ or Julia)

[1] Xiaoxing Xia, Christopher M. Spadaccini, and Julia R. Greer. Responsive materials architectured in space and time. Nature Reviews Materials, 7(9):683–701, Sep 2022.

[2] Ying Li, Wei Li, Tiancheng Han, Xu Zheng, Jiaxin Li, Baowen Li, Shanhui Fan, and Cheng-Wei Qiu. Transforming heat transfer with thermal metamaterials and devices. Nature Reviews Materials, 6(6):488–507, Jun 2021.

[3] Chuong Nguyen, Xiaoying Zhuang, Ludovic Chamoin, Xianzhong Zhao, H. Nguyen-Xuan, and Timon Rabczuk. Three-dimensional topology optimization of auxetic metamaterial using isogeometric analysis and model order reduction. Computer Methods in Applied Mechanics and Engineering, 371:113306, 2020.

[4] Jie Gao, Huipeng Xue, Liang Gao, and Zhen Luo. Topology optimization for auxetic metamaterials based on isogeometric analysis. Computer Methods in Applied Mechanics and Engineering, 352:211–236, 2019.

[5] Duy Vo, Pruettha Nanakorn, and Tinh Quoc Bui. Geometrically non-linear multi-patch isogeometric analysis of spatial Euler–Bernoulli beam structures. Computer Methods in Applied Mechanics and Engineering, 380:113808, 2021.

[6] Mian Zhou, Liang Gao, Mi Xiao, Xiliang Liu, and Mingzhe Huang. Multi-scale topology optimization of cellular structures using nitsche-type isogeometric analysis. International Journal of Mechanical Sciences, 256:108487,2023

[7] Brandon L. Talamini and Raul Radovitzky. A discontinuous Galerkin method for nonlinear shear-flexible shells. Computer Methods in Applied Mechanics and Engineering, 303:128–162, 2016.

[8] Saurav Sharma, Cosmin Anitescu, and Timon Rabczuk. A discontinuous Galerkin method based isogeometric analysis framework for flexoelectricity in micro-architected dielectric solids. arXiv preprint arXiv:2311.15073, 2023.

[9] Sai Kubair Kota, Siddhant Kumar, and Bianca Giovanardi. A discontinuous Galerkin/cohesive zone model approach for the computational modeling of fracture in geometrically exact slender beams. Computational Mechanics, Jul 2024.

[10] T. Hirschler, R. Bouclier, P. Antolin, and A. Buffa. Reduced order modeling based inexact feti-dp solver for lattice structures. International Journal for Numerical Methods in Engineering, 125(8):e7419, 2024.

[11] J.C. Ji, Quantian Luo, and Kan Ye. Vibration control based metamaterials and origami structures: A state-of-the-art review. Mechanical Systems and Signal Processing, 161:107945, 2021.

[12] Fan Wu, Xin Zhang, Pu Xue, and M. S. Zahran. Multi-scale concurrent topology optimization of frequency- and temperature-dependent viscoelastic structures for enhanced damping performance. Structural and Multidisciplinary Optimization, 66(11):234, Nov 2023.

[13] Mathias Schmidt, Lise No¨el, Keenan Doble, John A. Evans, and Kurt Maute. Extended isogeometric analysis of multi-material and multi-physics problems using hierarchical B-splines. Computational Mechanics, 71(6):1179–1203, Jun 2023.

Collaborations envisagées

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