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Multiobjective topology optimization of hyperelastic lattices for strain-tunable wave filtering

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Abstract

Excessive vibrations in engineering systems can compromise performance, fatigue life and comfort, and may also lead to noise amplification, loss of precision in sensitive components, and increased maintenance requirements. These challenges motivate the development of adaptive wave-filtering materials. This work addresses this need by developing a topology optimization framework to design 2D hyperelastic lattices with strain-tunable band gaps around a user-defined target frequency. The key concept is that the lattice should not filter vibrations in its undeformed configuration but should selectively block wave propagation near the target frequency once it is deformed, enabling on-demand wave filtering. The methodology combines finite-strain hyperelasticity to compute the deformed configuration with a wave analysis based on Bloch–Floquet periodic conditions, formulated on both the undeformed and deformed unit cell, keeping the computational cost low while accurately capturing the dispersion properties of an infinite lattice. The optimization problem is posed as a multiobjective compromise: (i) maximize the emergence of a band gap around the target frequency in the deformed state, while (ii) maintaining the absence of such filtering in the undeformed state, and (iii) enforcing material continuity and manufacturability by coupling the design with a compliance objective of a tensile plate problem. This compliance term is a key novelty that acts as a physically meaningful regularization to promote material continuity, preventing the emergence of isolated material areas when the lattice is unimaterial (where these would be non-manufacturable and mechanically irrelevant), as well as improving numerical robustness and stability in bimaterial designs, where strong stiffness contrasts can otherwise trigger unstable topological updates. Topology evolution is performed using the Bidirectional Evolutionary Structural Optimization (BESO) technique, yielding 0/1 layouts without intermediate densities, producing manufacturable lattices, and avoiding the need for post-processing (relevant differences between the behaviour of the optimized cell and the final design). Numerical examples demonstrate the ability to generate reconfigurable lattices whose band structure can be switched “on” around the target frequency through controlled deformation, while preserving structural integrity and connectivity. F. Gómez-Silva acknowledges support of grants PID2024-156124NB-I00 and PID2021-123294OB-100, funded by MICIU/AEI/ 10.13039/501100011033 and by ERDF/UE and FEDER. R. Ortigosa and J. Martínez-Frutos acknowledge the support of grant PID2022-141957OA-C22 funded by MICIU/AEI/10.13039/501100011033 and by ‘‘ERDF A way of making Europe’’. They also acknowledge the support provided by the Autonomous Community of the Region of Murcia, Spain through the programme for the development of scientific and technical research by competitive groups (21996/PI/22), included in the Regional Program for the Promotion of Scientific and Technical Research of Fundacion Seneca - Agencia de Ciencia y Tecnologia de la Region de Murcia.

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