Multi-fidelity Optimization of an Acoustic Metamaterial using Model Order Reduction and Machine Learning

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Metamaterials are structures that are designed to show properties which cannot be observed in conventional materials [3]. One of those properties is the generation of a stop band, a frequency range in which vibrations are strongly attenuated. Metamaterials that show a stop band are often generated by a periodic repetition of a so-called unit cell. To assess the stop band behavior, a single unit cell is first discretized by means of the Finite Element Method. By applying periodic boundary conditions, the discretized undamped equation of motion turns into a dispersion eigenvalue problem with respect to the frequency and the wavenumbers. Since the quantity of interest are stop bands in the frequency range, real values for the wavenumbers are prescribed and the eigenvalue problem is solved for the frequency. Consequently, the eigenvalue problem has to be solved repeatedly for all possible values of the wavenumbers. Since the involved matrices are obtained by means of the Finite Element Method and thus can become very large, the stop band calculation for a single parameter point is computationally very expensive. [4]

In order to reduce the computational effort, models of lower fidelity, i.e. models that approximate the same output compared to the full order model but with a lower accuracy and a lower computational complexity, can be derived. For the stop band calculation, three different models of lower fidelity are used: (i) Model Order Reduction using the Generalized Bloch Mode Synthesis [2], which is a modal reduction method based on the Component Mode Synthesis. Furthermore, (ii) surrogate modeling is applied in order to estimate the objective function value without performing any Finite Element simulation. The surrogate model is thereby used via a surrogate-based adaptive optimization strategy [1]. Finally, the characteristics of the stop band computation are exploited: Since we are not interested in the relationship between frequencies and wavenumbers for all possible wavenumbers but only in a band in the frequency range, (iii) it is sufficient to solve the eigenvalue problem of the full order model for the two points in the wavenumber-space, for which the upper and the lower bound of the stop band occur. In order to learn these relevant values of the wavenumbers, machine learning methods, namely neural networks and polynomial regression, are used. The three models of lower fidelity are combined in a multi-fidelity optimization strategy to exploit the properties of each.

References

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