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Automatic Tracing of Dispersion Relations for Complex Waveguides via Machine Learning approach

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ABSTRACT

Guided ultrasonic waves have been applied as effective screening tools for a wide range of elongated engineering structures, due to their capability to propagate long distances and the flexibility in selecting mode-frequency combinations. For all applications, the computation of dispersion solutions (i.e. frequency-dependent phase/energy velocity and attenuation) as well as tracing of dispersion curves are essential. In dealing with complex waveguide problems, some numerical approaches such as the semi-analytical finite element (SAFE) method and the boundary element method (BEM) are usually exploited to obtain all the wavenumbers along the waveguide at discrete frequencies, wherein the tracing of varied guided modes largely relies on manual routines. However, it will become ambiguous and even impossible for such mode tracing in some special scenarios. For instance, the guided modes in anisotropic composite laminates would exhibit the mode coupling effect, thus having comparable particle displacements along all three orthogonal directions; the amount of existing high order modes dramatically increases in the irregularly-shaped structural features or in the leaky system, accompanying much more complicated wave behaviour.

This study thus explores the feasibility of using Machine Learning algorithms for automatic mode tracing in these complex waveguides. Eigen-wavenumbers and associated eigenvectors are solved through the SAFE calculation at given frequencies, from which the modal quantities and mode shapes can be extracted. An affinity propagation clustering technique is then adapted, which takes as input the measure of similarity between pairs of eigen-solutions. Real-valued messages are exchanged between all data points until a high-quality set of exemplars and corresponding clusters gradually emerges. The dispersion curves of guided modes that exist in an orthogonal composite plate, confined to a welded steel plate, as well as in an embedded pipe are well traced, respectively. The clustering results are also compared with that using the classical *k*-means approach for these case studies, showing substantial improvement. Since the proposed mode tracing scheme are free of frequency stepwise operation and thus can reduce the number of discrete frequencies to solve the eigenproblem, which leads to an immediate reduction of computational cost.

Keywords: automatic mode tracing, dispersion curves, clustering, complex waveguides