Spectrally accurate approximation of eigenvalue functions through overlapping radial basis function interpolants for structural optimization

Dimitri Bettebghor[1]

[1]ONERA - The French Aerospace Lab
29, Avenue de la Division Leclerc
dimitri.bettebghor@onera.fr

ABSTRACT

Many mechanical simulations involve eigenvalue computations: natural frequencies, buckling, stability of gyroscopic systems. Structural optimization and more generally engineering optimization require many evaluations of such eigenvalues leading to excessive computational times, especially for global optimization techniques. Accurate approximations of eigenvalues with respect to optimization variables that often are natural parameters of the mechanical systems are then required to alleviate the computational burden. Dependence of the critical eigenvalue with respect to these natural parameters (geometry, material, load case...) is often complex, part of the reason is that the critical eigenvalue is the minimum of several eigenvalues, resulting in a loss of differentiability for structural parameters where the critical eigenvalue becomes multiple [1]. This discontinuous derivative prevents from accurate approximation whenever the approximation model is smooth such as most of the standard approximation techniques (kriging, artificial neural network...[2]) Furthermore, such gradient discontinuities are known to degrade optimization algorithms convergence.

In this work, we present an original strategy that allows first to locate such gradient discontinuities of the quantity of interest (typically frequencies, buckling critical factor…) and next to build an accurate approximation model of this quantity. This approximation model is then used within an optimization process. Our original strategy assumes that the gradient of the eigenvalue functions is available and only needs a few sample points of the design space. Our strategy combines a classical approximation strategy (Radial Basis Function (RBF)) with advanced stastistical techniques. More precisely, our strategy takes into account this discontinuous behavior of the response to approximate by dividing the input space through the clustering of the gradient space. Radial basis interpolants are then constructed over each region and a patch region is defined that encompasses the non differentiable region. Such patch regions are defined with the help of a classical statistical classifier known as Support Vector Machines (SVM). Such SVM define a margin that is used to define the patch regions. The final approximation model is defined as a combination of different radial basis interpolants over these patch regions.

This strategy is tested over two different test cases. First, critical buckling factor of composite plates is approximated and second, cut-off frequency of a gyroscopic system is approximated with this original strategy. The accuracy of the approximation is compared with other advanced approximation strategy. Our approximation strategy shows excellent convergence rates and numerical results demonstrate that it is even possible to achieve spectrally accurate approximations for relatively low dimensional approximation problems (below 4). An application to composite structure optimization is also given.

References

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