Design-Space Dimensionality Reduction in Global Optimization of Functional Surfaces: Recent Developments and Way Forward

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In simulation-driven shape optimization of complex industrial products (such as aerial vehicles, ship hulls and appendages, propellers, turbomachinery components, and functional surfaces in general), there exists an inherent similarity between global optimization (GO) and uncertainty quantification (UQ): they rely on an extensive exploration of the design and operational spaces, respectively; often, they need local refinements to ensure accurate identification of optimal solutions or probability density regions (such as distribution tails), respectively; they both are dramatically affected by the curse of dimensionality as GO and UQ algorithms' complexity and especially computational cost rapidly increase with the problem dimension. Therefore, there exists a natural ground for transferring dimensionality reduction methods for UQ to GO. These enable the efficient exploration of large design spaces in shape optimization, which, in turn, enable global optimization (possibly in a multidisciplinary and stochastic setting). The paper reviews and discusses recent techniques for design-space dimensionality reduction in shape optimization, based on the Karhunen-Loève expansion (equivalent to proper orthogonal decomposition and, at the discrete level, principal component analysis [1]), spanning from geometry-based approaches to physics-informed formulations, and from linear to nonlinear approaches. A recent methodological advancement, namely the parametric model embedding [2], is also introduced, which is very attractive for use with CAD/CAE software in the industrial context. Examples are shown and discussed for the RANS-based hydrodynamic optimization of ship hulls.

References

[1] Diez, M., Campana, E.F. and Stern, F., 2015. Design-space dimensionality reduction in shape optimization by Karhunen–Loève expansion. Computer Methods in Applied Mechanics and Engineering, 283, pp.1525-1544.

[2] Serani, A. and Diez, M., 2023. Parametric model embedding. Computer Methods in Applied Mechanics and Engineering, 404, p.115776.