A spline dimensional decomposition for high-dimensional uncertainty quantification

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Abstract

A spline dimensional decomposition (SDD) of a square-integrable random variable, comprising hierarchically ordered measure-consistent orthonormal basis splines (B-splines) in independent random variables, is introduced. A dimensionwise decomposition of a spline space into orthogonal subspaces, each spanned by a reduced set of measure-consistent orthonormal B-splines, results in SDD. Using the modulus of smoothness, the SDD approximation is shown to converge in mean-square to the correct limit. Analytical formulae are proposed to calculate the second-moment properties of a truncated SDD approximation for a general output random variable in terms of the expansion coefficients involved. Numerical results from an elastostatic problem in 15 stochastic dimensions indicate that a low-degree SDD approximation with an adequate mesh size generates a significantly more accurate estimate of the output variances than a high-order approximation from existing polynomial chaos expansion or polynomial dimensional decomposition. The SDD method proposed is most suitable in the presence of locally nonlinear or nonsmooth behavior found in applications.