Reduced-order modeling for uncertainty quantification in cardiac electrophysiology

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ABSTRACT

We develop a computationally efficient framework to perform uncertainty quantification (UQ) in cardiac electrophysiology in order to improve the ability of cardiac models to reproduce both physiological and pathological patient-specific behaviors. These numerical models, obtained from the discretization of parametrized partial differential equations (PDEs), are inevitably affected by uncertainty, e.g., in (i) the computational domain, (ii) physical coefficients and (iii) boundary conditions. We address a complete UQ pipeline, including: (i) a variance-based sensitivity analysis for the selection of the most relevant input parameters; (ii) forward UQ (or uncertainty propagation) to investigate the impact of intra-subject variability on clinically relevant outputs related to the cardiac action potential; (iii) backward UQ (or parameter and state estimation and data assimilation) in view of both model calibration and personalization. In particular, Bayesian methods provide a rigorous framework for the solution of backward UQ problems: sampling algorithms, such as the Markov chain Monte Carlo (MCMC) or the (ensemble) Kalman filter, enable to estimate the distribution of quantities of interest (model parameters, state of a system) from noisy clinical measurements. Numerical strategies for UQ problems involve the approximation of PDEs for several (usually, order of thousands) input parameter values, thus making high-fidelity, or full-order, techniques (e.g. the finite element method) ill-suited. To mitigate this computational burden, we replace the high-fidelity model with computationally inexpensive projection-based local reduced-order models aimed at reducing the state-space dimensionality. ROM approximation errors on the outputs of interest are finally taken into account by means of statistical error models built through Gaussian process regression, enhancing the accuracy of the whole UQ pipeline.

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