Fast Parameter Inference in a Computational Model of the Left-Ventricle using Emulation

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Biomechanics modelling of the heart can provide insight into heart function and help to improve treatments for heart diseases. A commonly used approach is nonlinear hyperelastic modelling of the left ventricle (LV) myocardium based on the Holzapfel-Ogden constitutive law (H-O law) [1], which typically has eight material parameters. A grand challenge of applying such a model to patient-specific studies, however, is to estimate these material parameters inversely based on in-vivo clinical measurements. This is because the forward modelling is extremely computationally expensive, and limited in vivo data (P-V curve and strain) make it difficult to find the global minimum of the loss or objective function (quantifying goodness of fit) in the inverse process. Hence, a direct application of the modelling is not suitable for designing personalised treatments within clinics where decisions have to be made in real time.

In this work, we propose to use the concept of statistical emulation to infer the material parameters of healthy volunteers in a viable clinical time frame. Emulation methods avoid simulating from the LV model by replacing it with a surrogate model inferred from previous simulations generated before the arrival of a patient at the clinic. These forward simulations can be run by massive parallelisation before a patient arrives. We compare and contrast two emulation strategies: (a) emulation of the outputs of the computational model and (b) emulation of the loss between the observed data for the patient and the computational model outputs. These comparisons are also performed for two different types of statistical models: (1) Low Rank Gaussian Processes (GPs), using the equivalent basis-function representation, with hyperparameters estimated using generalised cross validation, and (2) local GP emulation based on the K nearest-neighbours of the point of interest in parameter space. The predictive performance of each combination of methods is assessed on test data simulated from the computational model for given inputs obtained using a Sobol sequence. The estimated material parameters are then compared with the multi-step optimization procedure proposed by Gao et al. [2] using the traditional modelling approach. Our emulation results not only give good agreement to those of [2], but also show a 4-5 orders of magnitude reduction in computational time. Finally, we discuss the importance of the LV geometric features and the feasibility of using a reduced parameter set of the H-O law for the LV modelling.

References

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