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Energy preserving reduced-order cardiovascular models for augmented hemodynamics monitoring

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For anaesthetists, monitoring is the gateway for patient care during anaesthesia. It includes blood pressure and flow and electrical activation derivated data. From this clinical motivation, we develop biophysical reduced-order models of the cardiovascular system and model-fusion methods based data assimilation approaches. We apply these methods in the context of anaesthesia paving the way to augmented monitoring.

We first build an appropriate cardiovascular model. In general anaesthesia, blood pressure wave propagation plays an important role in physiological features of interest: the dicrotic notch and peak pressure value, but only global quantities are considered. We therefore select from the literature a reduced left ventricle model [1] and a 1D-arterial model [2] and propose a thermodynamically consistent coupling between them. To obtain robust numerical simulations, we aim to derive energy consistent time-discretisations. This approach also allows to provide consistent estimates of energetic quantities that are used as biomarkers by the doctors: e.g. ventricular work or heart efficiency. The strategy here is to express energy quantities as quadratic forms through changes of variables and use midpoint discretisation. Counterparts to the thermodynamical relations at the continuous level are obtained at the discrete level [3]. To tackle the parameter estimation throughout the surgical procedure (such parameter values may vary in time) we develop adapted Kalman filter estimators for nonlinear model. As a preliminary validation, we test the estimation procedure using observations of the central pressure and the aortic blood flow on a database of 45 real patients. We simplify the model using a two-element windkessel to represent the arterial circulation, the measurement location being upstream of the arterial circulation. We show that the calibrated model fits the data while providing meaningful parameter estimates and that the estimator is capable of capturing the expected changes of contractility and distal resistance value induced by drug administration.

Finally, the natural persective is to combine the estimation method and cardiovascular model introduced above in order to use the ordinary radial pressure measurements.

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