Inferring arterial viscoelasticity parameters from data using Physics-Informed Neural Networks

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Accurate estimation of arterial viscoelastic properties is essential for realistic modeling of cardiovascular hemodynamics. In one-dimensional fluid–structure interaction models, the relationship between pressure and vessel deformation is governed by both elastic and viscous effects. Viscous effects can play an important role in the blood flow but are often disregarded due to the difficulty of measuring them with accuracy.

In particular, arterial walls can be described using a Standard Linear Solid (SLS) model, where the pressure–area relation includes an elastic contribution and a viscoelastic term responsible for energy dissipation and waveform damping. Following the formulation in the reference model, this can be expressed as

$$\partial_t p + d(A)\,\partial_x(Au) = S(A,p), \tag{1}$$

where t is time, x is the longitudinal direction along the arterial centerline, A is the cross-sectional area of the artery, p is the arterial wall transmural pressure, $d(A)$ represents the elastic contribution, typically parameterized through the stiffness coefficient, and $S(A,p)$ accounts for viscoelastic effects depending on parameters such as the asymptotic modulus and the relaxation time. These parameters control key physiological behaviors such as pressure peak attenuation and hysteresis.

One way of extracting this viscoleastic parameters from measured pressure, flow or arterial cross-sectional area data are Physics-Informed Neural Networks (PINN). The model is trained by minimizing a composite loss function combining data fitting and physical consistency,

$$\mathcal{L}(\Theta) = \mathcal{L}_{\mathrm{PDE}} + \mathcal{L}_{\mathrm{data}}, \tag{2}$$

where $\mathcal{L}_{\mathrm{PDE}}$ enforces the governing equations of the system, $\mathcal{L}_{\mathrm{data}}$ penalizes the mismatch with observed pressure, flow, or area data, and Θ includes the set of trainable parameters of the viscoelastic model to be reconstructed and the weights and biases of the PINN. This formulation enables the simultaneous reconstruction of both the hemodynamic fields and the underlying viscoelastic parameters, which are often very difficult to estimate.