Validation of a sequential data assimilation method applied to cardiac electrophysiology

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Improved electroanatomical recordings and imaging capabilities prompts for trying to personalize cardiac electrical models. Though it is challenging, data assimilation is a family of methods relevant to this problem. It consists in estimating the state of the system thanks to observations. Among the two main approaches, variationnal and sequential, we choose to investigate the possibilities of a sequential method based on an atrial model and atrial electroanatomical maps. The method combines a state observer and a Kalman filter to estimate some parameters in the model.

First, we simulate a sinus rythm coupled to different pacing scenarios using a validated realistic atria model, see [3], summarized as :

$$\begin{cases} A_m\left(C_m\dfrac{\partial u}{\partial t}^{(k)} + f(u^{(k)},t)\right) - \mathrm{div}(\sigma^{(k)}u^{(k)}) \\ \qquad = (-1)^k\gamma(u^{(1)}-u^{(2)}) \qquad (1) \\ \dfrac{\partial w}{\partial t}^{(k)} = g_{CRN}(u^{(k)},w^{(k)}) \end{cases}$$

The anatomical geometry was segmented from clinical MRI, while the electrophysiology is based on the Courtemanche ionic model and monodomain equations on coupled surfaces (endo and epicardum, labeled $k=1,2$) so as to efficiently represent transmural effects. Activation times were then recorded in the left atria, and provide a number of *in silico* electroanatomical maps.

For the data assimilation work, these maps are projected on a coarser mesh of the left atria only. We applied to a simpler monodomain model the Luenberger observer devised by A. Collin & al. [2]. In addition the conductivity parameters were estimated using a Reduced-order-Unscented-Kalman-Filter (RoUKF) [4] in order for the simplified model to fit the recorder maps. Eq. 2 states both the observer and the filter :

$$\begin{cases} A_m\left(C_m\dfrac{\partial \tilde{u}}{\partial t} + f(\tilde{u},t)\right) - \mathrm{div}(\sigma\nabla\tilde{u}) = \mathscr{G}_L(z,\tilde{u}) \\ \dfrac{\partial w}{\partial t} + g_{MS}(\tilde{u},w) = 0 \qquad (2) \\ \dot{\theta}(t) = G_\theta(D(z,\tilde{u})) \end{cases}$$

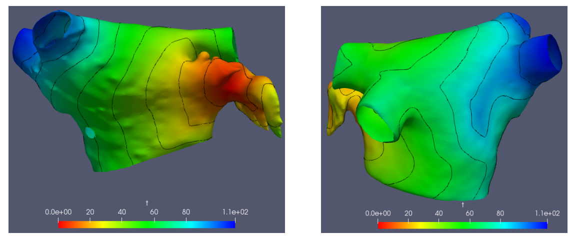

FIGURE 1 – Reconstructed activation map

Firstly, we tried to estimate a unique parameter α such that the conductivity tensor $\sigma = \alpha\,\mathrm{Id}$ is isotropic. Secondly, we tried to estimate two conductivities parameters g_l and g_t such that the conductivity tensor is $\sigma(x) = g_t\,\mathrm{Id} + (g_l - g_t)f(x)\otimes f(x)$, where the unit vector $f(x)$ points towards the fiber direction.

In order to validate the data assimilation technique, we compared the activation maps coming from a monodomain simulation with estimated parameters, to the originally recorder activations maps.

All simulations were done using Verdandi library [1] developed by M3DISIM Research team and the software CEPS developed by Carmen Research team.

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