Front observer for data assimilation of electroanatomical mapping data for a numerical atrial model

A Gérard, Annabelle Collin, J Bayer, A Frontera, Philippe Moireau, Yves Coudière

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A. Gérard[1,2,4,5,6], A. Collin[4,5,7], J. Bayer[1,4,5], A. Frontera[1,9], P. Moireau[8], Y. Coudière[1,2,4,5,6]

[1] IHU Liryc, Electrophysiology and Heart Modeling Institute, F-33000 Pessac-Bordeaux, France
[2] Univ. Bordeaux, CRCTB U1045, Bordeaux,
[3] Inserm, CRCTB U1045, Bordeaux, F
[4] Univ. Bordeaux, IMB UMR 5251, Talence, F,
[5] CNRS, IMB UMR 5251, Talence, F
[6] Carmen Research Team, Inria, Talence, F,
[7] Monc Research Team, Inria, Talence, F,
[8] M3disim Research Team, Inria, Saclay Île de France, F,
[9] Bordeaux University Hospital (CHU), Bordeaux, F

Introduction

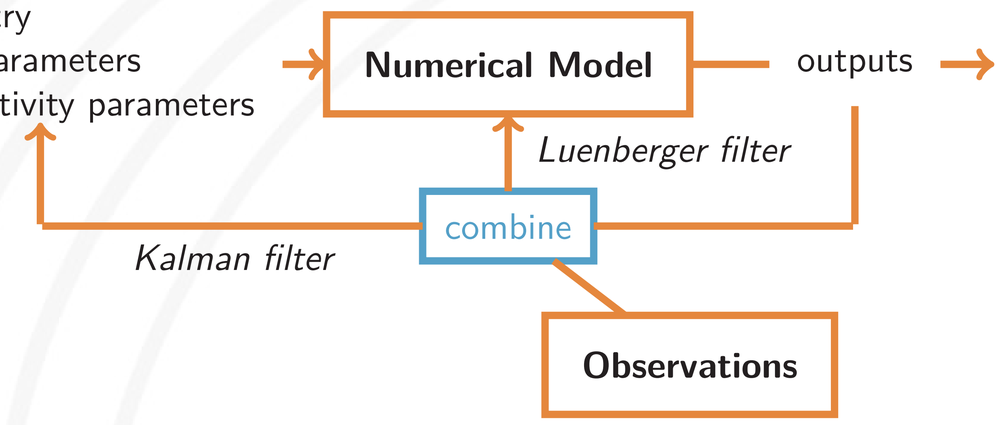
In this study, we aim at developping a method to fit an atrial numerical model to some patient's data. We want to use *data assimilation techniques* therefore.

The bilayer model of the atria from [1] provides a good basis. Our objective is to adjust it to data from electroanatomical maps of any patient, in the most automatic way.

Data assimilation provides a natural way to combine a numerical model and incomplete observations.

Principle of data assimilation

- geometry
- ionic parameters
- conductivity parameters



The model is based on the geometry and structure, from MR images and from our current knowledge (e.g fibre directions, and conduction parameters). It is complemented with a priori ionic parameters.

The outputs of the model are compared to some given observations (any electrical data), so as *to minimize a distance between the model and the observation*.

The model is modified accordingly, and provides new outputs...

Method: a Luenberger observer

We introduce a Luenberger observer of the propagation in a surface atrial model, like in [2]. The observer can pursue the actual activation front reconstructed from the observations.

It amounts to add a term in the bilayer model which compares the state of the model with the available observations, *only on the endocardial layer*, as follows:

$$\underbrace{\lambda\,\delta\left(\Gamma_u, x\right) dJ(u)}_{\text{error on the shape}} + \underbrace{\mu\,\left(1+\operatorname{sign}\left(dJ(u)(u-c_{\text{th}})\right)\right) dJ(u)}_{\text{error on the topology}}.$$

- The coefficients $\lambda \geq 0$ and $\mu \geq 0$ (called "gain") are set arbitrarily.
- The error is measured with the quantity

$$J(u) := \int_{\Omega_u^{in}} \left(z - C_1(\Omega_u^{in})\right)^2 d\Omega + \int_{\Omega\setminus\Omega_u^{in}} \left(z - C_2(\Omega_u^{in})\right)^2 d\Omega,$$

defined such that

$$\text{The observation and the data match} \Leftrightarrow J(u) = 0.$$

- The domain Ω_u^{in} is the region depolarized at time $t > 0$ in the model;
- The function z denotes the observation, and the numbers C_k are given by

$$C_1(\Omega_u^{in}) = \frac{\int_{\Omega_u^{in}} z dx}{\int_{\Omega_u^{in}} dx}, \quad C_2(\Omega_u^{in}) = \frac{\int_{\Omega\setminus\Omega_u^{in}} z dx}{\int_{\Omega\setminus\Omega_u^{in}} dx}.$$

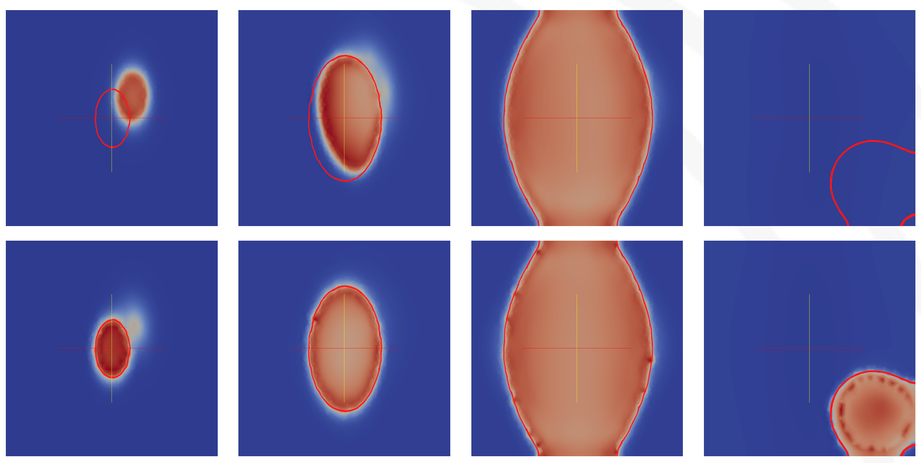
The error on the shape correct the location of the activation front.

The error on the topology track any breakthrough of an new activation site.

Test case 1: in-silico data

An activation map is build from a numerical model with *2 sites of excitation* (center at time $t = 0$ and lower right corner at $t = 250$ ms).

The model is run with a single excitation at a wrong location, shifted upper right, see top left image on the figure below.

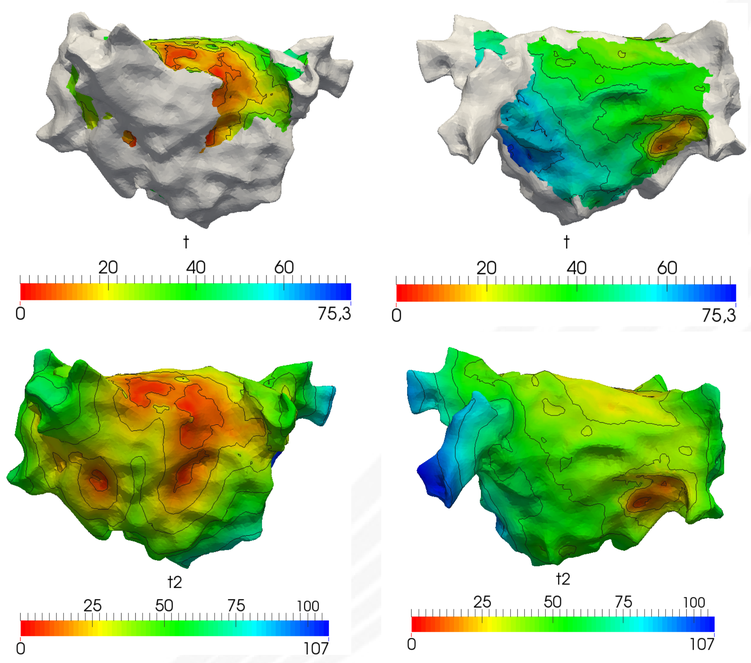


- From left to right: the action potential (red=depolarized, blue=resting state) at times $t = 5,\ 8,\ 13,\ 265$ ms;
- The red line shows the measured (in-silico) activation front;
- Top row: the model corrected only by the error on the shape;
- Bottom row: the model corrected by both errors.

A breakthrough at any time can be captured by the model.

Test case 2: a patient's data

This work is in progress, but we could run the model with the observer on both errors for a dataset acquired during a CARTO procedure for a patient with AF.



- Top row: activation map reconstructed from CARTO's LAT.
- Bottom row: activation map completed by data assimilation.

The mean and standard deviation of the difference between the observation and the data are, repsectively, 0.63 ms *and 0.97* ms.

Conclusion and future works

Our model can track an activation front from observed data, including breakthrough of wavefront at any time.

We have to incorporate a Kalman filter, in order to recover ionic and conduction parameters in the model. In addition, other quantities may be easily build with the model: phase maps, velocity fields, repolarization properties...

[1] Simon Labarthe, Jason Bayer, Yves Coudière, Jacques Henry, Hubert Cochet, Pierre Jaïs, and Edward Vigmond. A bilayer model of human atria: mathematical background, construction, and assessment. *Europace*, 16(suppl 4):iv21–iv29, 2014.

[2] A Collin, D Chapelle, and P Moireau. Sequential state estimation for electrophysiology models with front level-set data using topological gradient derivations. In *Functional Imaging and Modeling of the Heart*, pages 402–411. Springer, 2015.