# Personalization of Cardiac Motion and Contractility from Times Series of Images

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## Abstract

Personalization is a key aspect of biophysical models in order to impact clinical practice. In this paper, we propose a personalization method of electromechanical models of the heart from cine MR images based on a variational method. After estimation of electrophysiological parameters, the cardiac motion is estimated based on a proactive electromechanical model. Then cardiac contractilities on two or three regions are estimated by minimizing the discrepancy between measured and simulation motion. Evaluation of the method on three patients with infarcted or dilated myocardium is provided.

## 1. Introduction

Simulations of the cardiac function have reached such a degree of realism that it is now possible to compare them quantitatively with available cardiac images and signals acquired routinely on patients. This implies that it is now possible to personalize cardiac models, i.e. to optimize their parameters such that it behaves in adequacy with patient specific acquired data (images and signals). This personalization opens new avenues to impact the clinical practice by improving the diagnosis of cardiac diseases and planning therapies (such as Cardiac Resynchronization Therapy [1]) based on biophysical models.

To successfully estimate the parameters of an electromechanical model of the heart from time series of cardiac images (in our case, cine-MRI) is a complex task which is related to the problem of *data assimilation,* For instance, Moireau et al. [2] used reduced Unscented Kalman Filtering to estimate contractility parameters from synthetic image sequences. In this article, we present the results of an automated personalization method of an electromechanical model of the heart from catheterized electrophysiology data and cine MR images from three patients. Detailed description of the proposed approach can be found in [3].

## 2. Material and methods

In this study, we consider datasets from patients suffering from heart failure. The acquired data consists in intracardiac non-contact electrophysiology measurements as well as anatomical, late-enhancement and cine MR images. From anatomical MR images, the right and left ventricles are segmented and then registered to the late-enhancement images where scars and grey zone regions can be extracted. This leads to the creation of a patient-specific computational tetrahedral mesh of the heart where anatomical and pathological information is stored.

The personalization of the electromechanical model takes place in three stages: electrophysiological, kinematics and mechanical personalizations.

The former [4] consists in finding a set of global and local parameters (such as electrical conductivities...) of an electrophysiological model of the heart in order to minimize the discrepancy between simulated isochrones and measured isochrones. More precisely, from intracardiac catheters it is possible to measure the time at which depolarization and repolarization waves reach a given point in the right and left endocardia. The personalized depolarization and repolarization times are then used to control the active contraction force of the mechanical model described below.

Kinematics personalization consists in estimating the motion of cardiac structures from images. We use the same electromechanical model both to regularize the cardiac motion from cine-MR images and to estimate biophysical parameters. The kinematics personalization approach described in [5] is based on a proactive deformable model including three mechanical components: active contraction forces, passive biomechanics and image forces. Image forces are not physiology based since their sole purpose is to help tracking the cardiac motion. They are discarded during the next stage : mechanical personalization.

Indeed, mechanical personalization aims at estimating some mechanical parameters (in this paper, contractility parameters) such that they minimize a functional measuring the discrepancy between simulation and measurements, in our case the node positions previously estimated from the kinematics personalization using image forces. To optimize the functional, we use a variational data assimilation approach based on the adjoint model and evaluate it on three cine MRI cases. For each minimization step, the gradient of functional with respect to the seeked parameters must be evaluated. With the adjoint method, this is done by performing a forward simulation followed by a backward simulation which takes around 45 min on a regular PC, thus leading to computation times of 4 to 6 hours for the mechanical personalization.

## 3. Results

The proposed approach has been first evaluated on synthetic images where ground truth mechanical parameters are known. It was then applied to 3 datatsets from patients suffering from heart failure.

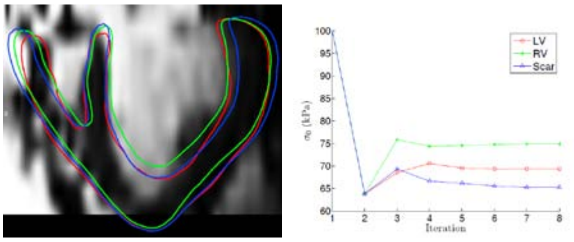


*Fig. 1. (Left) Cardiac meshes overlaid on image slice; green: with initial contractility parameters; blue : after mechanics personalization; red : target; (Right) Estimation of the 3 contractility parameters of the myocardium;*

In the first case, we have estimated the 3 contractilities from the right and left ventricle and the scar region (see Figure 1). A good convergence of the 3 parameters is reached with a lower contractility parameter in the scar region as expected. The RV contractility is greater than the LV one which may be explained by a greater ejection fraction measured in the RV than in the LV. The optimization decreases the mean distance error with respect to tracked motion over the whole cardiac cycle from 2.1 mm to 1.6 mm. The average error is comparable to the in-plane image voxel size (1.56 $mm^2$) but the maximum distance error was 9.7 mm which is significant. The region of largest errors is the base which may imply that the boundary conditions at the base should be improved. The end diastole is the time at which the average distance error is maximum (2.32 mm).

The personalization approach was also applied to two additional datasets of patients suffering from dilated cardiomyopathy. The estimated contractilities for the RV and LV are rather low especially for patient 3. The adjoint method leads to a decrease of the average distance error to 2.33 mm for patient 2 and 2.19 mm for patient 3 for images with respective isotropic voxel size of 1.44 mm and 1.52 mm.

## 4. Discussion and Conclusion

We presented a new method for the automated mechanical personalization of cardiac models and applied it to several clinical cases including electrophysiology and cine MRI data.

One limitation of this work is that it is restricted to the estimation of a limited number of contractility parameters defined on prescribed regions. One could iteratively refine the number of regions where parameters are estimated in a coarse to fine manner.

Those results are nonetheless encouraging and their analysis can help improving the model and the parameter set to be optimized. Those personalized models may serve to plan various therapies (e.g. Cardiac Resynchronization Therapy) by predicting the cardiac function after testing several therapeutic strategies *in silico*.

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