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Segmentation of left ventricle on dynamic MRI sequences for blood flow cancellation in Thermotherapy

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ABSTRACT

In this paper, we develop a new semi-automated segmentation method to cancel the unstable blood flow within the left ventricle (LV) in cardiac magnetic resonance (MR) images with parallel imaging. The segmentation is performed using a deformable model driven by a new external energy based on estimated probability density function (pdf) of the MR signal in the LV. The use of signal distribution through the data allows us both to pull the contour towards the myocardium edges and to ensure the smoothness of the curve. Since data for each slice are acquired with the GRAPPA parallel imaging technique, the spatial segmentation is followed by a temporal propagation to improve the convergence in terms of quality and rapidity. Experiments demonstrate that the proposed model provides better results than the results of three state-of-the art methods based on Active Contour Model, which should facilitate the use of the method for clinical purposes.

1. Introduction

Cardiac Magnetic Resonance Imaging (MRI) has evolved beyond a diagnostic imaging device to a modality which is used to perform cardiovascular interventions. The MR capability to provide quantitative thermometric measurements has been used to guide and monitor invasive thermal ablation treatment such as radiofrequency (RF) ablation of cardiac arrhythmias [1].

In order to perform On-line MR thermometry, imaging must be fast to fit the real-time monitoring process. For this, a sequence EPI (Echo Planar Imaging) is combined with GRAPPA (Generalized Autocalibrating Partially Parallel Acquisition) imaging that allows for considerable reduction of motion artifacts and for reducing data sampling time. Nevertheless, physiological motion artifacts are often observed because of heart deformation, respiratory activity of subjects and also blood flow within the heart chambers.

On MRI acquisition sequences, it is not always possible to cancel the blood flow signal in the heart chambers using saturation techniques [2]. (see Fig. 1a). Moreover, this type of cancellation will be very time-consuming since it is necessary to determine the period of time (the timing) during the cardiac cycle when the blood is better cancelled. This requires performing an exhaustive research on the time interval corresponding to the diastole. In all cases, cancellation of the blood signal is not always perfect as the blood flow in the ventricle is not unidirectional.

The blood flow signal may disturb the quality of motion estimation at the endocardium which is the interface between the cardiac cavity and the heart muscle. Decreasing the quality of the motion estimation in this region may decrease information about the thermal dose that accounts for the effectiveness of the thermal ablation process.

In Fig. 1b and c, are shown two types of *in vivo* images. The left image is acquired with a saturation band placed as shown in Fig. 1a, allowing canceling the blood signal within the left ventricle. In the right image, the blood signal appears as an inhomogeneous signal within the left ventricle.

In this work, we propose to cancel the blood flow by segmenting the left ventricle (LV) in image sequences. In other words, delineating this heart chamber allows excluding blood pixels from motion estimation process. Therefore the estimated motion at the interface between the heart muscle and the interior of the cavity is no more disturbed by this unstable signal.

The segmentation of the heart chambers is a very active area of research in the field of medical image analysis [3,4]. Indeed, clinicians often need to assess the characteristics of cardiac muscle such as size, shape, mass and ejection fraction [5]. Many cardiac LV segmentation methods have been studied to calculate these characteristics using MRI. In this paper, a spatio-temporal LV segmentation algorithm for cardiac cine MRI images using an active contour model is presented. Taking

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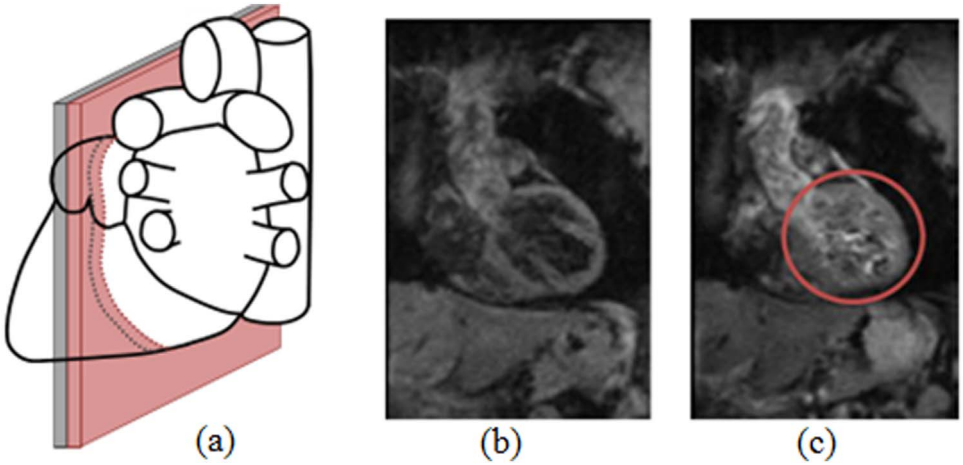

Fig. 1. Blood signal cancellation using saturation technique. (a) Setting the saturation band (red) before the MR slice (in gray) to cancel the blood flow signal. (b) MR image with cancellation of blood signal. (c) MR image without cancellation of blood signal.

into account the GRAPPA-type acquisitions where both time of scanning and signal to noise ratio (SNR) are reduced, delineating the structures of interest using deformable models poses considerable challenges. On one hand, contour evolution must take into account the noise which follows a non-central chi (nc-χ) distribution in the case of multichannel surface-coil arrays acquisition. As a solution, the design of the data-driven term can be adapted to this constraint. On the other hand, computation time must be reduced and compatible with real-time MR temperature monitoring.

A large amount of noise estimation methods for noise removal has been reported in the literature in the case of multichannel surface-coil arrays acquisition. Considering the non central-χ distribution Aja Fernandez et al. [6] proposed to estimate its parameters, in particular the variance. Assuming that the background of the image is central-χ distributed, a maximum likelihood estimator was developed to estimate the noise variance from the background mode of the image histogram. However, if the background is not present and the SNR is high, the real MR signal is supposed to be corrupted with an additive gaussian noise. Thus, its variance can be estimated like the variance of gaussian noise [7]. In addition, Rajan et al. [8] proposed an extension of the LML method [9] used when MR images are Rician distributed, to deal with the nc-χ distributed data using a Linear Minimum Mean Square Error (LMMSE) estimator.

In our case, the pdf of the signal corrupted with noise is used to improve the segmentation by driving the proposed deformable model. In other words, we have created a new external energy term that uses the estimation of signal distribution in MR images. Our new force allows measuring the probability of each of pixel to belong to the LV and hence pulling the active contour towards the myocardium boundary. The extracted contour is then propagated through the whole time series in order to reduce the computational time for convergence.

The content of this paper may be summarized as follows. In Section 2, an overview of existing active contour methods used in LV segmentation is presented. In Section 3, the theory behind the active contour models and the noise distribution in MR images are explained then our spatial and temporal active contour model is proposed in Section 4. Section 5 presents the experimental results. Finally, conclusions and perspectives are drawn in Section 6.

2. Related work

Extensive surveys of existing cardiac ventricles segmentation techniques can be found in the review of Frangi et al. [4] as well as in the recent work of Petitjean et al. [3] who provides an excellent overview and classification of proposed techniques.

The different methods known from the literature use various image processing techniques. In [3] the authors distinguish between five main classes of cardiac ventricle segmentation techniques including thresholding, edge-based and region-based approaches, pixel-based classification, and atlas-guided approaches. Furthermore, numerous segmentation approaches incorporate prior knowledge of the anatomy or biomechanics of the heart to increase their robustness and accuracy. According to the levels of information used during the segmentation process, approaches can also be categorized as no prior, weak prior or strong prior [3]. Image-driven techniques, such as thresholding, region-based or edge-based techniques, or pixel classification, offer a limited framework for strong prior incorporation. Deformable models, including snakes and their variants, on the contrary, offer a great, versatile framework for using either weak or strong priors.

Since the introduction of snakes by Kass et al. [10], deformable models have been widely used in the segmentation of the left ventricle either in the parametric framework (snakes) or in the implicit one using level sets [11,12]. This methodology uses an initial curve which is then iteratively moved by applying an energy function in order to fit one or more structures of interest. The energy function is a set of forces that drive the initial contour to the desired object boundaries.

A number of methods have been proposed that dealt with the design of external forces. Santarelli et al. [13] proposed an automated edge-based active contour method for myocardium border detection in anatomic and perfusion studies with Magnetic Resonance. Firstly, data undergo a non-linear anisotropic filtering. Then, filtered images are segmented by application of the Gradient Vector Flow (GVF) snake procedure. Also, Liang et al. [14] proposed a radial-GVF snake that simplifies snake energy functions from 2D to 1D using the so- called transform image. Transform image defines the region of interest in polar coordinates. Thus, a line-like constraint is incorporated into snake energies in order to extract the endocardium contour first. After the endocardium extraction, the modified GVF external force reactivates snake towards epicardial contour. Another external force named gradient vector convolution (GVC) is added by Wu et al. [15] for the proposed active contour model. Moreover, a circle-shape based energy is integrated into the GVC snake model to extract the endocardium of the LV. After the endocardium has been detected, the original edge map around and within the endocardium is directly set to zero. This modified edge map is used to generate the new GVC force field, which pushes the snake contour directly to the epicardium by employing the endocardium result as initialization. Pluempitiwiriyawej et al. [16] presented a novel active contour scheme, called the stochastic active contour scheme (STACS).The employed energy functional includes stochastic modeling of the image textures and shape priors, in addition to the usual edge-based and contour smoothness terms. Paragios proposed in [17] a coupled propagation of the epicardial and endo-