A Semi-Automatic Ventricular Border Segmentation Package Based on Multi-Phase Levelset Segmentation

Q. Duan[1], D. Moses[2], M. B. Srichai[2], V. M. Pai[2], A. F. Laine[1]

[1]Biomedical Engineering, Columbia University, New York, NY, United States, [2]Radiology, New York University Medical Center, New York, NY, United States

Introduction

Cardiac volume cine-MRI images are becoming more important in clinical diagnosis. In order to quantitatively evaluate such cardiac functional image data, segmentation of endocardial and epicardial boundaries of the myocardium is essential. However, in clinical applications, manually segmentation of ventricular borders from the relatively large stack of image data can be extremely tedious and time-consuming limiting usefulness. Due to the anatomical variation among patients and different acquisition protocols, cardiac MR image quality can vary significantly. However a fully automated ventricular border segmentation, especially epicardial border segmentation, remains a non-trivial problem. We propose a semi-automated ventricular border segmentation package with minimal human intervention.

Method

A multi-phase level set method [1], an approach used widely for MRI and ultrasound image segmentation, underpins the core segmentation algorithm. A temporal 3D segmentation algorithm is implemented because the acquisition of cardiac cine-MRI is usually time-wise for each 2D short axis view at each slice location. A fully-automated 2-phase level set method is first used to outline the endocardial surface of the left ventricle. Epicardial surface segmentation is a special case of the 4-phase level set algorithm, in which two coupled level set functions are used. One of these level set functions, corresponding to the blood pool, is set to be stationary as an indicator of the endocardial border. The other level set function is used to segment the myocardium surrounding the blood pool. Due to the relatively complex anatomic surroundings and partial volume effects, the epicardial border usually appears with fuzzy at some locations. In order to increase the robustness of segmentation, edge information extracted from a 3D over-complete dyadic wavelet expansion [2] was used to provide a second information channel. The level set method was then expanded to a *multi-channel* version. The package also includes a 2D active contour algorithm for handling cases where intensity inhomogeneity is too severe to be handled by the level set algorithm alone. The package was developed in the Matlab environment (The Mathworks, Natick, MA) with cross-platform compatibility. The segmentation was performed in the following order: 1) Data was pre-processed with a previously developed anisotropic diffusion [3], an intelligent edge preserving smoothing technique, to suppress noise, 2) Manual cropping of the first slice, at the endocardial borders were segmented, 3) Endocardial segmentation results were used as an automatic initialization for the epicardium segmentation algorithm, and 4) Final segmentations were pruned using automated morphological operations to obtain smooth boundaries. This was also used to minimize any inclusion of the papillary muscles in the endocardial segmentation.

Results

The proposed software package was tested on data obtained by two different cardiac MRI pulse sequences (FLASH and TrueFISP) acquired on 1.5T and 3T MRI systems (Siemens Medical Solutions, Malvern, PA). The images were acquired on one normal volunteer and two patients undergoing cardiac viability evaluation. The data analysis was undertaken with IRB approval. For each pulse sequence, image data from 25 time frames in seven different short-axis locations were acquired and used for the segmentation algorithm. Segmentation results were visually and qualitatively evaluated by human experts. Sample epi- and endocardial boarder segmentation results for the three cases are shown in Figure 1. Results from quantitative segmentation applied to one of the series were compared to the two experts' segmentation and shown in Table 1. The table shows that in terms of area difference and true and false positive regions, the variation between the proposed segmentation method and each human expert was comparable to inter-user variation observed between human experts. Also the level set based method showed better performance in segmenting epicardium than endocardium surfaces, due to the fact that excluding the papillary muscles was problematic at some cardiac phases . The segmentation took about 10 minutes for each pulse sequence (all slices) whereas manual tracing for the same data set typically required between one to two hours.

Conclusions

A semi-automatic package for segmenting along endocardial and epicardial boarders of the myocardium has been developed based on multi-phase level set method. The software package was tested on several different cardiac MRI image sets and evaluated by human experts who noted remarkable performance and reliability. Faster segmentation times, relative to manual segmentation, make it potentially useful for analyzing volumetric cardiac cine datasets obtained clinically.

References

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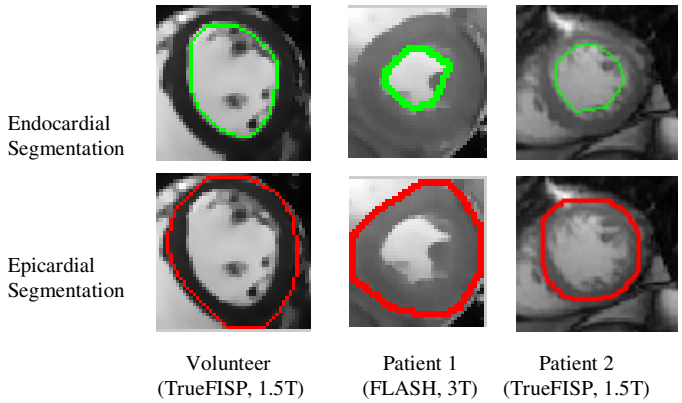

Figure 1. Illustration of segmentation results on different cardiac MRI data.

Table 1. Quantitative comparison between different segmentation methods.

%		Endo Seg	Epi Seg	Myo Seg
EP1 v.s. CAS	AD	17.4±4.0	4.3±3.0	31.3±10.6
	TP	82.4±4.2	96.2±1.6	91.4±3.4
	FP	0.3±0.5	8.0±2.8	39.9±8.4
EP2 v.s. CAS	AD	16.1±2.8	3.7±2.3	10.0±5.9
	TP	83.4±2.9	93.3±1.7	86.0±3.3
	FP	0.5±0.7	3.3±2.0	24.1±4.8
EP1 v.s. EP2	AD	3.5±2.5	7.8±3.2	19.4±8.4
	TP	93.9±3.1	99.1±0.7	92.1±3.6
	FP	4.6±2.0	8.7±2.7	27.3±7.6

EP1: expert 1
EP2: expert 2
CAS: computer aided segmentation
AD: area difference
TP: True Positive
FP: False Positive