A fully automatic segmentation method for myocardial boundaries of left ventricle in tagged MR images

Abstract

Purpose
The non-invasive examination of the cardiac functions is an important diagnostic, and follow up, tool for detection and evaluation of cardiovascular dysfunctions. Magnetic resonance (MR) cardiac tagging is a technique imposing temporary spatial variation in longitudinal magnetization around the heart area, so that temporary tag patterns deforming with cardiac motion can be captured in a sequence of MR images. The tag patterns play the role of noninvasive fiducial markers, by tracking of which accurate estimation of cardiac motion can be achieved *in vivo.* This motion pattern can be subsequently analyzed and any abnormalities can be detected and assessed. Segmentation of myocardium is an essential step for most of the approaches used to estimate dynamic displacement field since only the tag lines inside the myocardium are of importance for the deformation estimation. However, in most of the literatures, segmentation of myocardium is done manually, which involves a large amount of tedious, time-consuming and error-prone work. In this abstract a fully automatic segmentation method is proposed for delineation of myocardial boundaries in the tagged MR images.

Methods
A fully-automatic method has been developed by the authors to segment myocardium of left ventricle by identifying epicardial and endocardial contours using implicit active contour models driven by tag structures and constrained by shape priors. The method has been developed to work, and tested with a temporal short-axis sequences of tagged cardiac MR images acquired using the Space Modulation of Magnetization (SPAMM) protocol. MR data obtained using this technique exhibits crisscross of dark lines creating regular grid (Fig. 1a). Subsequent grid spatiotemporal deformations can be used to describe contractions of the myocardium. The proposed method consists of four major steps: (1) Segmentation of the whole heart by applying a modified Chan-Vese active contour model to the, so called, motion image (Fig. 1b). The motion image is defined as the summation of absolute temporal derivatives calculated for each image pixel over whole sequence of the tagged images; (2) Location of the left ventricle (Fig. 1c) in the first frame inside the segmented heart using a maximum *a posterior* (MAP) method calculated with a help of ring-like shaped kernel; (3) Estimation of the epicardial contours using active contour model with shape priors defined as a superposition of constraints forcing the estimated contour to have approximately elliptical shape and not to deviate too much from the

epicardial contour estimated in the previous frame. The active contour external forces are defined by a descriptor emphasizing the grid structure; (4) Estimation of the endocardial contours using active contour model with shape prior encouraging the estimated contours to be located inside and at a predefined distance from the corresponding epicardial contour estimated in Step 3. As in Step 3 the external forces are defined by a descriptor emphasizing the grid structure. The first two steps provide initialization for the epicardial contour estimate evolutions in the first frame. Subsequent spatiotemporal tracking of contours in Step 3 and Step 4 can be carried out frame by frame with the final contours in the previous frame as the initial contours in the current frame.

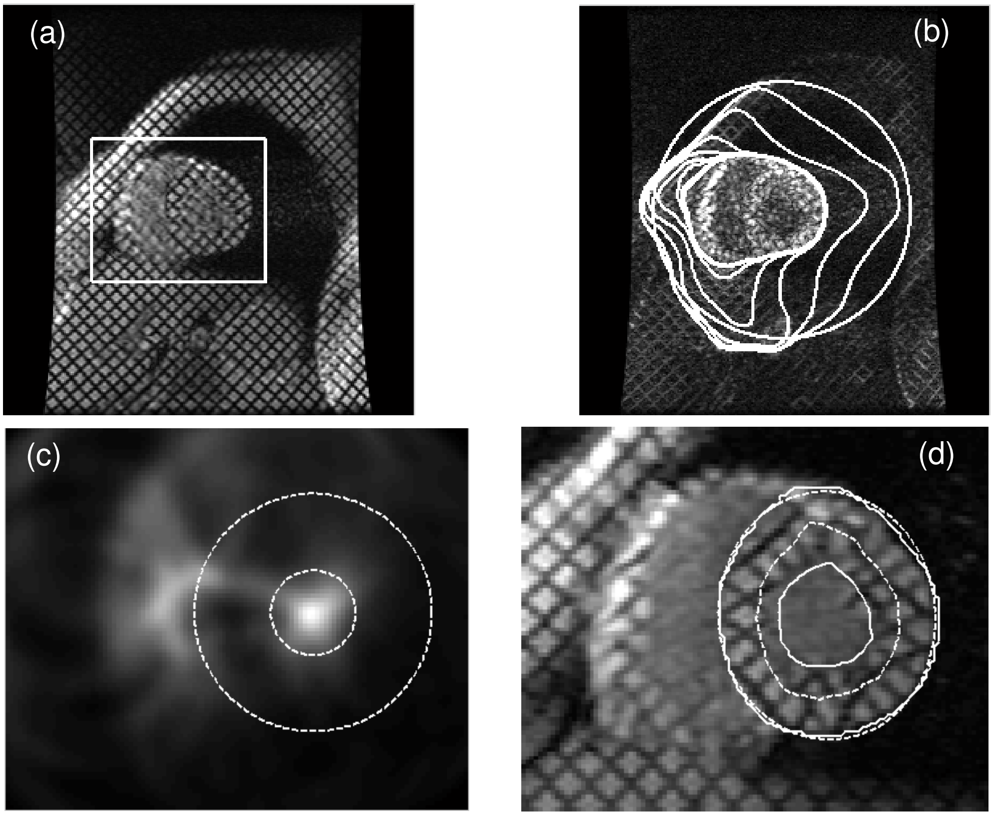

Figure 1 (a) Tagged cardiac MR image acquired using the SPAMM protocol with the grid of dark lines clearly visible. The rectangular area shown in the image represents part of the MR images which is automatically located from Step 2 and used for the myocardial boundaries estimation.

(b) Motion image with superimposed samples of the evolving contours taken every 8th iteration, with the initial circular contour and the equilibrium contour around heart (the most inner contour) also shown.

(c) A posterior distribution used to estimate position of the left ventricle, with overlaid contours centered at the position defined by the maximum of the distribution used as the initial estimated position of the left ventricle.

(d) Estimated epicardial and endocardial contours shown as solid lines, together with corresponding prior shape constraints shown as dash lines.

Results

The initial assessment of the proposed method was performed against manual segmentation carried out by clinicians. The evaluation data consisted of five data sets each containing five or six tagged MR images. The results obtained for the six images from the 3rd data set are shown in figure 2. It can be seen that in general there is relatively good correlation between manual and automatic delineation of the myocardial boundaries. It has to be noted that for the reported initial validation results no information is available about intra- or inter- observer variability and therefore it is impossible to quantitatively assess quality of the ground truth. Indeed a closer look at the images in figure 2 reveals that on some occasions (e.g. for image 2 and 5) the automatically selected contours are closer than the manual ones.

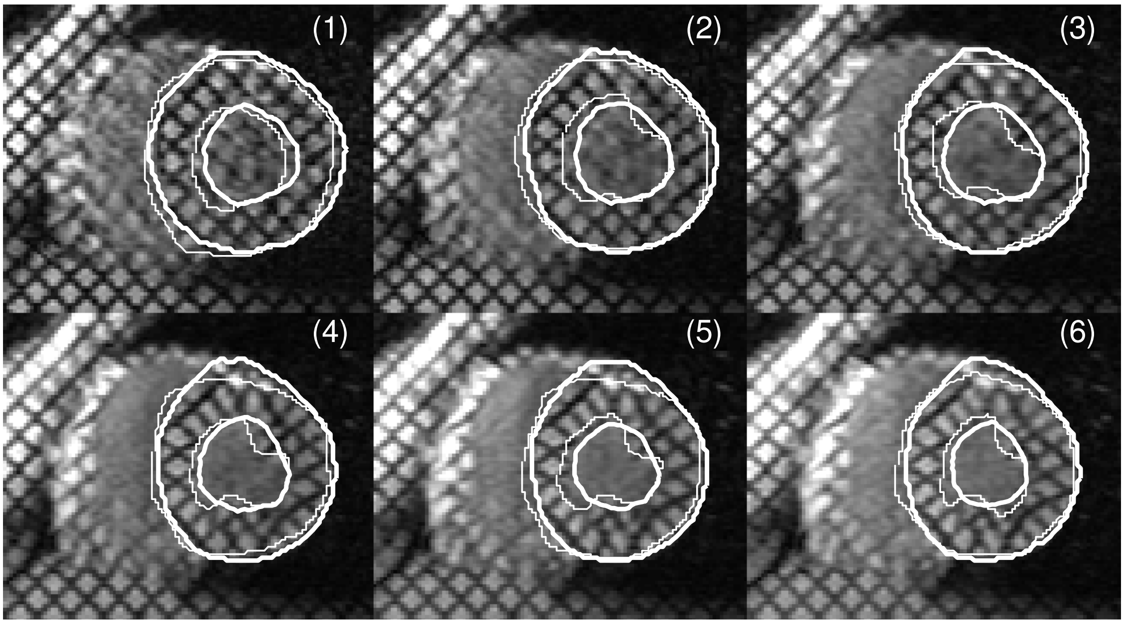

Figure 2. Result of the proposed automatic segmentation of the epicardial and endocardial contours shown as thick lines together with manual delineation represented by thin lines.

The quantitative evaluation of the proposed segmentation method against available ground truth is shown in Table 1. Two different error measures based on area-inside-contour and point-on-contour differences between the estimated and ground truth contours were used. The averages and standard deviations for both measures were calculated for each data set. The error measures were subsequently normalized by the quantity derived from the ground truth contours.

		Error (area) Mean (%)	Error (area) STD	Error (dist) Mean (%)	Error (dist) STD
Set 1	epicardium	8.42	0.027	7.88	0.072
	endocardium	10.13	0.026	8.60	0.058
Set 2	epicardium	6.31	0.021	5.61	0.045
	endocardium	8.06	0.017	7.36	0.056
Set 3	epicardium	6.93	0.013	6.21	0.045
	endocardium	18.54	0.021	14.04	0.097
Set 4	epicardium	4.75	0.016	4.21	0.038
	endocardium	15.52	0.040	11.57	0.077
Set 5	epicardium	5.50	0.015	5.02	0.043
	endocardium	16.15	0.040	13.58	0.131

Table 1. Quantitative comparison between manual (ground truth) and proposed automatic segmentation of the myocardial boundaries.

Conclusions

This abstract describes a novel fully automatic segmentation method for delineation of myocardial boundaries in the tagged MR images. The proposed method uses three different variants of the level set based active contour models for the delineation of the whole heart, epicardial and endocardial boundaries of left ventricle respectively. The initial qualitative and quantitative results obtained using the proposed method are given. The obtained results are very encouraging and are in principle in agreement with the results provided by manual delineation preformed by clinicians. Indeed in some cases the proposed automatic method seems to follow the apparent myocardial boundaries closer than the manual delineation. It is expected that the proposed algorithm could be instrumental in improving *in vivo* estimation of cardiac motion using tagged MR.