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Segmentation of the left ventricle in cardiac cine MRI using a shape-constrained snake model

Yuwei Wu, Yuanquan Wang *, Yunde Jia

Beijing Laboratory of Intelligent Information Technology, School of Computer Science, Beijing Institute of Technology, Beijing 100081, PR China

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ABSTRACT

Segmentation of the left ventricle (LV) is a hot topic in cardiac magnetic resonance (MR) images analysis. In this paper, we present an automatic LV myocardial boundary segmentation method using the parametric active contour model (or snake model). By convolving the gradient map of an image, a fast external force named gradient vector convolution (GVC) is presented for the snake model. A circle-based energy is incorporated into the GVC snake model to extract the endocardium. With this prior constraint, the snake contour can conquer the unexpected local minimum stemming from artifacts and papillary muscle, etc. After the endocardium is detected, the original edge map around and within the endocardium is directly set to zero. This modified edge map is used to generate a new GVC force filed, which automatically pushes the snake contour directly to the epicardium by employing the endocardium result as initialization. Meanwhile, a novel shape-similarity based energy is proposed to prevent the snake contour from being strapped in faulty edges and to preserve weak boundaries. Both qualitative and quantitative evaluations on our dataset and the publicly available database (e.g. *MICCAI 2009*) demonstrate the good performance of our algorithm.

1. Introduction

Cardiac magnetic resonance imaging has proven to be a versatile and noninvasive imaging modality. It can acquire the anatomical and functional information of a heart within a short period of time, and thus be widely used in clinical diagnosis [1]. The segmentation of cardiac magnetic resonance images (MRIs) is one of the most critical prerequisites for quantitative study of the left ventricle (LV). Many clinically established diagnosis indices such as wall thickness and ejection fraction are evaluated by the segmentation results of the LV.

In clinical practice, the LV segmentation task is often performed manually by an experienced clinician. The manual segmentation, however, is tedious, time consuming, subjective and irreproducible. This issue has motivated the development of automatically extracting contours of the LV. Although an impressive research effort has been devoted to automatic LV segmentation, it remains a challenging problem, mainly because of the difficulties inherent from MR cardiac images [2]. There have been extensive researches such as graph cuts [3,4], morphological operations [5,6], dynamic weights fuzzy connectedness framework [7,8], active contours or snake model [9–13,2] and supervised learning methods [14–17], to overcome challenges of the LV segmentation. Petitjean and Dacher [18] presented a comprehensive review of LV segmentation algorithms.

Among approaches mentioned above, the snake model is one of the most successful methods. It deforms a closed curve using both the intrinsic properties of the curve and the image information to capture the boundaries of the region of interest (ROI). However, the information (e.g. intensity, texture) only deriving from the image itself is not sufficient to get satisfactory segmentation results of the LV. The prior knowledge concerning the LV, therefore, is necessary to be incorporated into the snake model. In this paper, we propose an automatic LV segmentation method that addresses the following challenges: (1) image inhomogeneity; (2) effect of papillary muscle; and (3) lack of edge information. The proposed approach consists of the following steps as shown in Fig. 1:

(a) Automatic localization of the LV. Hough transform is applied to intensity difference image to locate the LV centroid and the ROI.
(b) Designing the external force for snake model. The external force field plays a leading role in driving the active contours to approach objects boundaries in the snake model, and thus significantly influences the segmentation performance. A novel external force called gradient vector convolution (GVC) is proposed. The GVC snake is of great capture range, and is much more robust toward detecting and preserving the weak edges.

* Corresponding author.
E-mail addresses: wuyuwei@bit.edu.cn (Y. Wu), yqwang@bit.edu.cn (Y. Wang), jiayunde@bit.edu.cn (Y. Jia).
URL: http://www.mcislab.cs.bit.edu.cn/member/wuyuwei/index.htm (Y. Wu).

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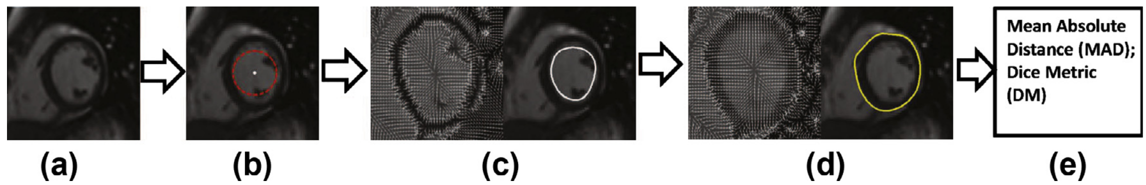

Fig. 1. Framework for segmenting the cardiac cine MRI. (a) The cardiac cine MRI input. (b) Automatic localization of the LV. (c) The external force of snake model for segmenting endocardium and the segmentation result. (d) The external force of snake model for segmenting epicardium and the segmentation result. (e) Evaluation of segmentation results.

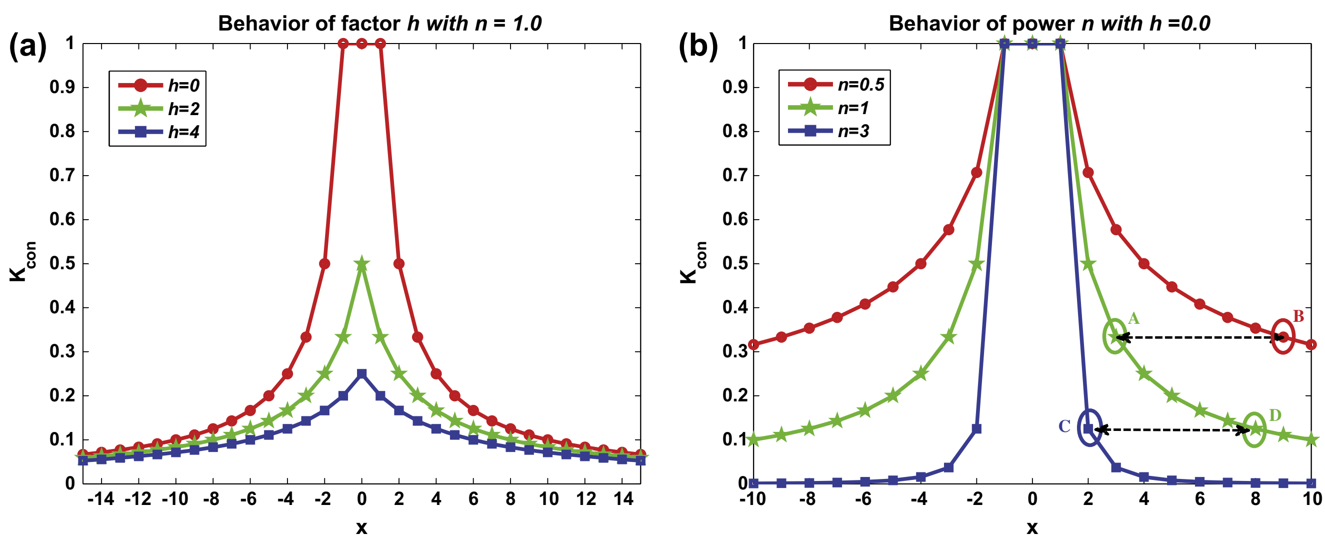

Fig. 2. Analysis of the behavior of h and n in 1D case.

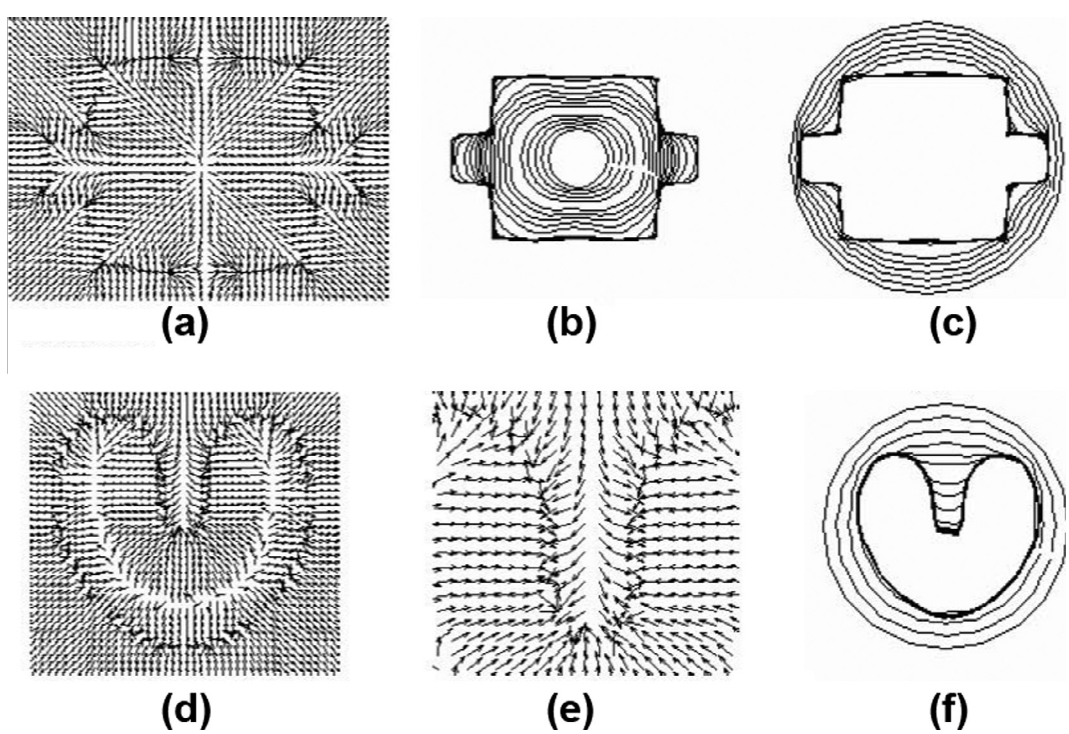

Fig. 3. The performance of GVC snake on U-shape and room images. (a) Is the GVC field of room image; (b and c) are the convergence of the GVC snakes with the initial contours inside and outside the room, respectively; (d) is the GVC field of U-shape image; (e) is the close-up of GVC field within the concavity; (f) is the convergence of the GVC snake on the U-shape image.