Computer Methods and Programs in Biomedicine 142 (2017) 109–116

Contents lists available at ScienceDirect

Computer Methods and Programs in Biomedicine

journal homepage: www.elsevier.com/locate/cmpb

A novel myocardium segmentation approach based on neutrosophic active contour model

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ARTICLE INFO

Article history:
Received 24 March 2016
Revised 9 February 2017
Accepted 15 February 2017

Keywords:
Myocardial contrast echocardiography (MCE)
Myocardium detection
Neutrosophic similarity
Active contour model

ABSTRACT

Background and objectives: Automatic delineation of the myocardium in echocardiography can assist radiologists to diagnosis heart problems. However, it is still challenging to distinguish myocardium from other tissue due to a low signal-to-noise ratio, low contrast, vague boundary, and speckle noise. The purpose of this study is to automatically detect myocardium region in left ventricle myocardial contrast echocardiography (LVMCE) images to help radiologists' diagnosis and further measurement on infarction size.

Methods: The LVMCE image is firstly mapped into neutrosophic similarity (NS) domain using the intensity and homogeneity features. Then, a neutrosophic active contour model (NACM) is proposed and the energy function is defined by the NS values. Finally, the ventricle is detected using the curve evolving results. The ventricle's boundary is identified as the endocardium. To speed up the evolution procedure and increase the detection accuracy, a clustering algorithm is employed to obtain the initial ventricle region. The curve evolution procedure in NACM is utilized again to obtain the epicardium, where the initial contour uses the detected endocardium and the anatomy knowledge on the thickness of the myocardium.

Results: Echocardiographic studies are performed on 10 male Sprague-Dawley rats using a Vivid 7 system including 5 normal cases and 5 rats with myocardial infarction. The myocardium boundaries manually outlined by an experienced radiologist are used as the reference standard for the performance evaluation. Two metrics, Hdist and AvgDist, are employed to evaluate the detection results. The NACM method was compared with those from the eliminated particle swarm optimization (EPSO) and active contour model without edges (ACMWE) methods. The mean and standard deviation of the Hdist and AvgDist on endocardium are 6.83 ± 1.12 mm and 0.79 ± 0.28 mm using EPSO method, 7.12 ± 0.98 mm and 0.82 ± 0.32 mm using ACMWE method, and 4.55 ± 0.9 mm and 0.58 ± 0.18 mm using NACM method, respectively. The improvement on epicardium is much more significant, and two metrics are decreased from 7.45 ± 1.24 mm, and 1.47 ± 0.34 mm using EPSO method, and 8.21 ± 0.43 mm, and 1.73 ± 0.47 mm using ACMWE method, to 4.94 ± 0.82 mm, and 0.84 ± 0.22 mm using NACM method, respectively.

Conclusions: The proposed method can automatically detect myocardium accurately, and is helpful for clinical therapeutics to measure myocardial perfusion and infarct size.

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1. Introduction

Myocardial infarction (MI) is one of serious heart diseases, and the infarcted area can lead to the subsequent death of cardiomyocytes and vascular cells in the border area. The key point to reduce the mortality associated with MI is to limit and reduce infarct size [1]. Therefore, detecting myocardium and assessing infarction size are critical in the study of morphology and function of myocardium [2].

Automatic delineation of the myocardium in echocardiography is used to aid the diagnosis of heart problems, such as ischaemia, by enabling quantification of wall thickening and wall motion abnormalities. Distinguishing between myocardial and non-myocardial tissue is, however, difficult due to a low signal-to-noise ratio, low contrast, vague boundary, speckle noise and other indeterminacy information.

Myocardial contrast echocardiography (MCE) is a non-invasive diagnostic technique providing information of cardiac function and

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http://dx.doi.org/10.1016/j.cmpb.2017.02.020
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hemodynamics. This has been used to obtain information of both MI and myocardial ischemia for the diagnosis purpose [3–5]. However, most methods based on MCE have relied on manual visual analysis, leading to errors of operator subjectivity; the accuracy of manual analysis in detecting on myocardium borders depends on the investigators' experience and their ability to distinguish artifacts from actual perfusion defects. It is evident that accurate and automatic detection of myocardium on MCE is a critical and valuable step and few studies have addressed the problem [6–8].

Computer aided diagnosis (CAD) system has been developed to identify the infarcted myocardium [9]. Many approaches have been proposed to identify and track myocardial borders [10], the ventricular cavity (i.e. endocardium) [11], epicardial boundary [12], and the full myocardium using echocardiographic images [13,14].

Ziwirn et al. [8] presented an endocardial boundary (inner boundary) detection method in myocardial images characterized by low signal-to-noise ratios. It converted the frames in Cartesian coordinates into polar coordinates, and applied a set of filters in order to compute the initial estimation of the endocardial boundary. The final estimation of the endocardial boundary was produced by an error correction process using both spatial and temporal filtering. The estimated boundaries are converted into Cartesian coordinates, for display. However, it is not a fully automatic approach and it needs manually defined reference points. Zhang et al. [10] presented a method to globally affine register a real time 3-D ultrasound volume to a 2-D cardiovascular MR image. The local phase presentation of both images was utilized as an image descriptor of "featureness". Phasemutual information was employed as the similarity metric. The registration process was built in a multi-scale frame-work to estimate the global affine transformation using a differential technique. However, its accuracy depends on the registration process which is time consuming. Sigit et al. [11] used collinear and triangle equation algorithms to detect and reconstruct the boundary of the cardiac cavity. It employed high boost filter to enhance the high frequency component and the morphological and thresholding operators to eliminate noise and convert the image into a binary image. Finally, the collinear and triangle equations are used to detect and reconstruct the more precise cavity boundary. Seng et al. [12] proposed an automated left ventricle detection method for two-dimensional echocardiographic images that could serve as an initialization for deformable models. The proposed approach consists of pre-processing and post-processing stages. The pre-processing stage enhances the overall contrast and reduces speckle noise, whereas the post-processing enhances the segmented region and avoids the papillary muscles. It only provides an initial contour of the left ventricle. Dietenbeck et al. [15] proposed a method to segment the whole myocardium in 2D echographic images. A level set model constrained by a shape formulation allowed to model both contours of myocardium. It can segment the whole myocardium for the four main views used in clinical routine. Dietenbeck et al. [14] extended a level-set method to track the whole myocardium in echocardiographic sequences. It enforced temporal coherence by adding a new motion prior energy to the existing framework, which was expressed as new constraint that enforces the conservation of the levels of the implicit function along the image sequence. However, it needs multiple views to finish the detection.

In different CAD approaches, myocardium segmentation and detection is a crucial step whose performance further analysis on functional measures of myocardium and fraction size. Lynch et al. [16] presented a level-set segmentation of the myocardium of the left ventricle of the heart by using a priori information in magnetic resonance imaging (MRI). Two fronts representing the endocardium and epicardium boundaries of the left ventricle were evolved as the zero level-set of a higher dimension function. A stopping term was introduced using both gradient and region-based information. Wong et al. [17] proposed a velocity-constrained front propagation approach for myocardium segmentation from magnetic resonance intensity image (MRI) and its matching phase contrast velocity (PCV) images. The curve evolution criterion was defined on the prior probability distribution of the myocardial boundary and the conditional boundary probability distribution, which was constructed from the MRI intensity gradient, the PCV magnitude, and the local phase coherence of the PCV direction. For the first image frame, a gradient marching level set step was used to approach the boundary, and a narrowband was formed around the curve. The initial boundary was then refined using the full information from priors and all three image sources. For the other frames, the resulting contours from the previous frames were used as initialization contours, and refinement steps were taken. However, the curve evolution criterion depends on the prior probability which is related to the training dataset. Li et al. [18] presented a semi-automated segmentation method for short-axis cardiac CT and MR images. It used two different energy functions for endocardium and epicardium segmentation to account for their distinctive characteristics, proposed a dual-background model for representing intensity distributions of the background in epicardium segmentation, designed a shape prior term, and estimated myocardium thickness using edge information. Lynch et al. [19] developed a segmentation approach to extract the epicardium and endocardium boundaries of the left ventricle using multi-slice and multi-phase MRI images of the heart. The images were segmented using a diffusion-based filter followed by an unsupervised clustering technique, and the resulting labels were checked to locate the cavity on left ventricle. The wall between these two bloodpools was measured to give an approximate thickness for the myocardium, and then it was used to find appropriate segments of the epicardium boundary. However, selection of the clustering number is a challenging problem.

A stochastic deformable model was proposed for the segmentation of the myocardium in MRI [20]. The segmentation was posed as a probabilistic optimization problem in which the optimal time-dependent surface was obtained for the myocardium of the heart in a discrete space of locations built upon simple geometric assumptions. The segmentation solution was obtained by the maximization of the posterior marginal for the myocardium location in a Markov random field framework which optimally integrated temporal-spatial smoothness with intensity and gradient related features in an unsupervised way by the maximum likelihood estimation of the parameters of the field. Lempitsky et al. [21] treated the segmentation problem as a two-class 3D patch classification task, solving it using random forests to obtain delineations of myocardium. However, this method is sensitive to noise which often occurs in medical images. Recently, machine learning methods such as random forest have been used to segment the myocardium in MCE [22]. It used a statistical shape model of the myocardium to guide the random forest segmentation. Lempitsky et al. [23] employed random forest classification for delineation of myocardium. It treated the segmentation problem of myocardial and non-myocardial tissue as a two-class classification task.

Although these methods are useful, most of them are semi-automatic segmentation algorithm and applicable to traditional ultrasound images and do not work well on the MCE image due to its own characteristics. Therefore, it still remains a challenge for CAD systems to properly and automatically segment and detect myocardium on MCE images. MCE images retain some properties that cause indeterminancy: i.e. vague boundaries, high amount of speckles, low contrast between suspicious areas and tissues. Therefore, dealing with the indeterminacy is necessary to improve the quality of images analysis on MCE. In this paper, we propose a novel CAD approach for fully automatic myocardium segmentation on MCE image based on neutrosophic similarity measurement and

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