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Nonrigid registration of cardiac DSCT images by integrating intensity and point features

Qinlan Xie*, Zhao Chen, Hong Chen, Xuesong Lu

School of Biomedical Engineering, South-Central University for Nationalities, Wuhan 430074, China

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ABSTRACT

In order to obtain accurate anatomical information for the whole heart, we propose a nonrigid registration method combining mutual information with the marching cubes method. Certain points are regarded as prior knowledge of the shape landmarks of cardiac structures. The registration process for the heart image can be divided into two steps: coarse alignment and accurate registration. The coarse alignment uses affine transformations to localize and center the image of the heart, and the accurate registration uses a B-spline method to constrain the deformation field. Mutual information combined with feature point pairs are used as the similarity measure function. All 15-dimensional feature descriptors are used to identify matched point pairs between marching cubes points in atlas intensity images and other points in the neighborhood of target images needing segmentation. Adaptive stochastic gradient descent optimization is used to obtain optimal registration parameters. Two groups of experiments show that the proposed method achieves higher registration accuracy than traditional ones based only on mutual information. They indicate that accurate anatomical information of the whole cardiac structure can be obtained.

1. Introduction

With the improvement of living standards, the incidence of and mortality due to cardiovascular [1] disease is also increasing. Early quantitative evaluation of the cardiovascular system thus becomes more and more important. Advanced Dual-Source Computed Tomography (DSCT) technology [2] can quickly obtain the shapes of anatomical structures, such as the coronary arteries and cardiac chambers, due to its high resolution in time and space. Different cardiovascular diseases show different pathological morphological characteristics. Extracting the morphological information from DSCT images can help to quantitatively diagnose cardiovascular disease.

Many different approaches have been proposed for the segmentation of the heart image. Popular methods include model-based approaches, graph-based approaches and registration-based approaches. Lombaert [3] et al. efficiently used the established graph cut method for the segmentation of the heart image. However, the total heart was segmented as a single object, including all chambers and myocardial muscles. Ecabert [4,5] et al. introduced a model-based approach for the full segmentation of the whole heart image (four chambers, myocardium, and great vessels). Unfortunately, the chambers were not segmented at the same time, resulting in inconsistent atrioventricular overlapping. Some researchers [6,7] have indicated that automatic registration-based segmentation for the whole heart image is an effective method for extracting heart information.

Medical image registration allows the anatomical points in two images to achieve consistency in their spatial locations by looking for a mapping relationship. The current registration methods can be divided into two classes: feature-based and intensity-based. The latter method uses intensity-based similarity metrics, such as cross-correlation (CC) [8] or mutual information (MI) [7,9,10]. The process does not take advantage of spatial information and has high computational complexity, even after optimization. Wolfgang [10] et al. observed that the occurrence of artifacts can hamper or slow down the alignment process. Interpolation, in combination with registration, often introduces spurious local maxima in the calculated MI function. The feature-based methods utilizing spatial information focus on the extraction of feature points, lines, or surfaces for the paired feature sets in registration. One disadvantage of this method is that it does not fully describe anatomical information, resulting in difficulty estimating the transformation parameters accurately. The blurred boundaries between small anatomical structures can easily cause mis-alignment [11,12].

The feature-based registration methods often extract fewer feature points due to their lack of prior knowledge of anatomical shapes. For example, the Scale Invariant Feature Transform (SIFT)

* Corresponding author.
E-mail address: xieqinlan@126.com (Q. Xie).

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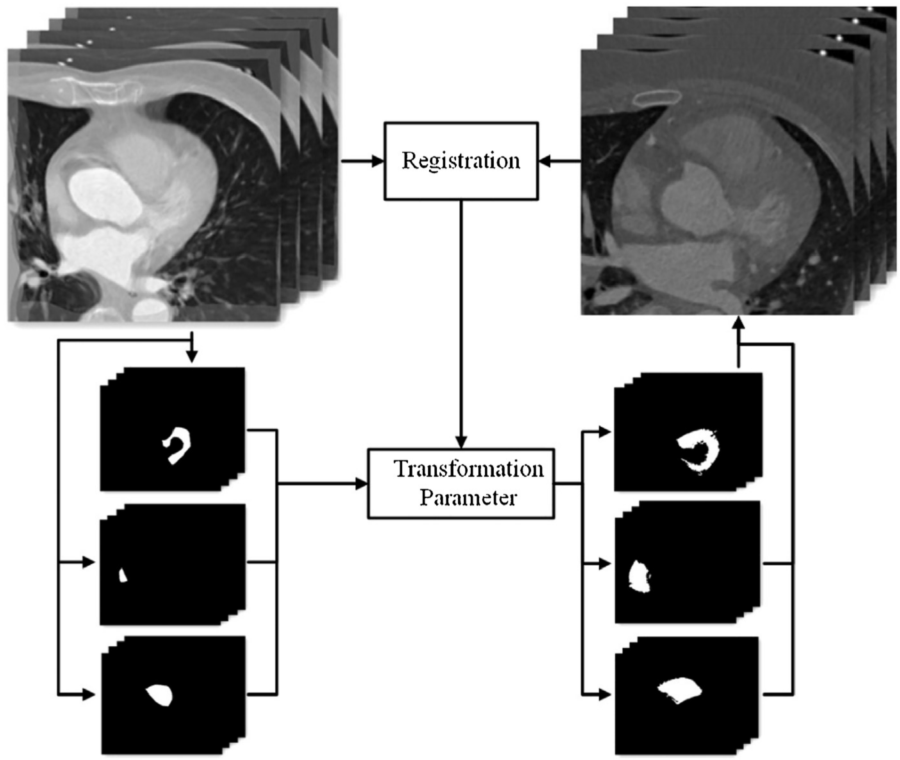

Fig. 1. The segmentation framework based on registration. The left upper side shows atlas intensity images, and target images are on the right. From top to bottom of the left column are the binary images of the LVM, RA and RV. The right column shows automatic segmentation results for the whole heart image.

[13] algorithm has this problem. To handle it, we introduce the marching cubes (MC) [14,15] method into the extraction of many marginal point sets, which represent anatomical shapes as prior knowledge. The number of matched points along the anatomical tissue edges is sufficiently large to permit the use of this method. Hence, the medical image registration can deal with more complex deformation of anatomical structures. In this paper we suggest a registration method based on mutual information combined with shape point information to implement precise registration-based segmentation for the whole heart image.

2. Method

The proposed method exists in the general context of registration-based segmentation processes in medical imaging. Some details about the implementation of the method are described below. We first characterize a registration-based propagation framework for automatic segmentation of the whole heart image in Section 2.1. In Section 2.2 we sketch how to extract the feature points and form matched point sets. The procedure and criterion, incorporating prior shape points into the registration framework, are presented in Section 2.3. Finally, in Section 2.4, the actual cost function for the proposed method is given.

2.1. Registration-based propagation framework

In the registration-based segmentation propagation framework (see Fig.1), the atlas intensity images are registered to the target images to be segmented with two main steps. First, global rough alignment and local accurate registration are implemented to localize the heart and find optimal correspondence between the atlas intensity images and the target images. Second, some substructures of the heart, including the left ventricle (LV), left ventricle myocardium (LVM), left atrium (LA), right ventricle (RV) and right atrium (RA), referred as to atlas binary images, have been segmented manually before registration. Using the optimal parameters from the first step, transformations of binary images are performed. The whole heart segmentation is done with different binary images, each of which corresponds to different parts of the heart anatomy.

Automatic segmentation for the whole heart image is achieved through the above framework. In Fig.1, the left upper side shows atlas intensity images, and target images are on the right. From top to bottom of the left column are the binary images of the LVM, RA and RV. The right column shows automatic segmentation results for the whole heart image.

2.2. Extraction of shape feature points

The Marching Cubes method is used to extract the shape landmarks of some substructures from the atlas binary images. A decimation process is implemented in order to reduce the number of points. The method of Schroeder [16,17] is used to specify a target decimation rate (98%) with respect to the original candidates. The remaining points form the shape landmarks of these substructures in atlas binary images. Through preliminary registration between the atlas intensity images and the target images, the landmark points from the atlas binary images are propagated to the target images, as shown in Fig.2, where the LVM is used as an example. Finally, coarse corresponding points are formed. We suppose that the accurate points are located in a $n_x \times n_y \times n_z$ neighborhood of the coarse corresponding points in the target images. To trade-off between computation time and registration accuracy, $n_x = n_y = n_z = 12$ is chosen by experiments.

2.3. Feature points matching

Feature vectors from images are needed to accurately match the landmarks of the atlas intensity images with the corresponding points of the target images. Features that describe the local