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Three-dimensional lung medical image registration based on improved demons algorithm

Xiaoqi Lu, Hefeng Yu*, Ying Zhao, He Hou, Yinhui Li

School of Information Engineering, Inner Mongolia University of Science and Technology, Baotou 014010, China

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A B S T R A C T

To put forward an accurate and effective registration method based on improved Demons algorithm, and to register three-dimensional pulmonary medical images of the same individual whose lung has the deformation under different respiration state. The experimental data are the maximum and minimum respiratory phase of the three-dimensional pulmonary images within a cycle of respiratory movement. First, images for registration are registered globally and non-rigidly. Feature points are extracted and matched by scale invariant feature transform algorithm. Afterwards, the global registration is finished according to the transformation parameter computed based on matching results. Finally, images after global registration are registered non-rigidly utilizing improved Demons algorithm. Image registration of human lung is realized employing improved method. The mean-square error between images before registration is 25,835.3 and it is reduced to 11,790.9 after registration. After further deal with improved Demons algorithm, the mean-square error between images is reduced to 3726.31 and the descent rate of mean-square is up to 85.58%. The proposed method effectively registers three-dimensional pulmonary images, which provides a solid foundation for doctors to estimate pulmonary respiratory movement and analyze respiratory function.

1. Introduction

Medical image registration technique is the basis and prerequisite of developing operation plan, image guided surgery, image-guided radiotherapy, medical image fusion processing and postoperative effect evaluation and so on, which has important clinical application value. For example, doctors can finish the registration process of images between the lesion image after cone-beam CT scan and the planned CT image in the image guided radiotherapy. Until the registration is finished, central position of target area is computed to get the adjustment parameter, which is need for treatment couch to adjust online [1]. At the same time, most of human organs are non-rigid, such as lung, heart, liver, etc. So studies about non-rigid medical image registration of non-rigid image have important significance [2].

At present, lung diseases are probed mainly through CT (computed tomography) technology. Multi-slice spiral CT scans can form high-resolution tissue slice images, it is able to demonstrate the organizational structure of lung lesions area clearly [3]. Four-dimensional computed tomography technology can fast and accurately form cross sectional images, which is to determine lung tumor location, and to capture the trajectory of tissues and organs, so it can delineate the target volume of radiotherapy, calculate the distribution of the radiation and measure setup error values more accurately [4].

There are various registration algorithms in the field of medical image registration, based on the different features calculated of registration algorithm, registration algorithm can be divided into feature-based registration algorithm and gray-based registration algorithm. Feature-based registration algorithm extract related features of images to be registered, including point features, linear features, contour and curve features and surface features, to match the feature sets of the two images. After the matching, it computes iteratively the optimal registration parameters by the relationship between the feature sets. Due to the information extracted is less than the total information of image, the information is little in iterative calculation. The algorithm has high efficiency, so it can make transform parameters convergence to the optimal value quickly. However, feature-based registration algorithm also exists the issue that whether the extracting and matching features are accuracy for the images to be registered or not, which directly affects the registration results directly. The gray-based registration algorithm often need to use part or all of the image information, and it can avoid error in extracting and matching features when

* Corresponding author. Tel.: +86 15550679816.
E-mail address: hetangfengqi@yeah.net (H. Yu).

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using the feature-based registration algorithm, in which the registration algorithm based on mutual information usually has more precision and more robust result than the feature-based registration algorithm, it can be used for multi-modal medical image registration, and the result of registration algorithm is less affected by the image quality. A non-rigid registration method based on matching algorithm of feature points is proposed by Wang et al. [5]. Feature points of images to be matched is extracted with scale invariant feature transform algorithm. The matching relationship between corresponding points is established by bidirectional matching algorithm to improve the registration accuracy. Then it uses normalized mutual information and particle swarm optimization to find the optimal transformation parameters. Wang et al. [6] proposed an improved registration algorithm on the basic of traditional variational optical flow model. Because the energy function of traditional method is flawed, making the algorithm can't handle the issue that uneven brightness and abnormal lesion area and over-smoothing well, so use improved data term and an adaptive anisotropic regularization term to resolve, at the same time add the feature matching term to the improved algorithm to solve the registration problem of large deformation medical images. By the above considerations, the hierarchical registration scheme proposed combines the characteristic of the two registration algorithms. The registration scheme through global registration can improve convergence speed of local registration, and the Demons algorithm which has diffeomorphism can make local deformation more accurate. Experimental results show that the improved registration scheme compared with conventional registration scheme, it can achieve registration of three-dimensional lungs images with greater deformation. The registration accuracy of images improved greatly with stronger robustness and higher application value.

2. Method and design

2.1. Registration algorithm based on feature extraction

Features extracted with scale invariant feature transform algorithm have the characteristic that the translation, rotation, zoom, brightness, noise, illumination changes, visual changes between images are kept invariable and stable. The feature points between images can be matched effectively with generated multi-dimensional feature vector [7,8], which is helpful to realize the large deformation of registration between images. For 3D image processing, the registration algorithm is mainly composed of three steps: First, feature detection and generation, feature detection of the reference image and floating image is, respectively, executed to generate feature vectors. Second, matching feature vector, relationship between the reference image and floating image is established with feature vectors. Finally, the thin plate spline transformation is executed.

2.1.1. Feature detection and generation

The scale space of three dimensional images is established with linear transformation kernel, that is, Gaussian convolution kernel. Images in adjacent layers are processed with difference to produce images with difference of Gaussian scale space. The generation of image scale space is shown as Fig. 2.1. In Gaussian scale space, there are M orders images in the Gaussian scale space. There are $S+3$ layers in each order in which images have the same size. The Gaussian kernel is set as $ki\sigma(i=0, 1, \ldots)$. And Gaussian kernel of the first order Gaussian smoothing images is $\sigma, k\sigma, \ldots, kS+2\sigma$, respectively. The images are downsampled by half in each dimension at each order, generating images of the first order with the same size as the original image, 1/8 the size of first order at the next order. And each order is processed in this way. The difference of

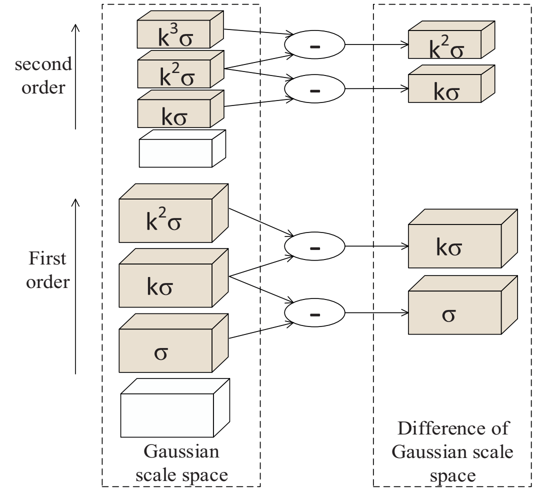

Fig. 2.1. Image scale space.

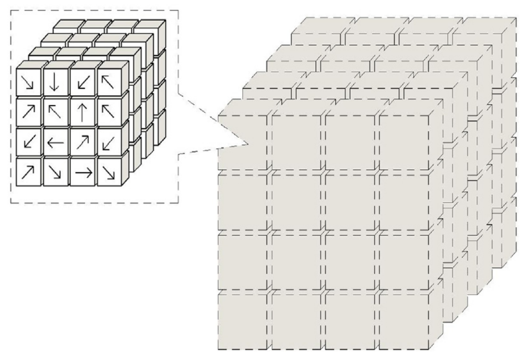

Fig. 2.2. Generating feature vectors.

Gaussian scale space is obtained by processing the adjacent layers of Gaussian scale space with difference. So there are M orders images and each order has $S+2$ layers. The gray of each voxel is compared with its adjacent voxels, the corresponding voxels in the adjacent scale layers and the adjacent voxels of the corresponding voxels in the difference of Gaussian scale space. According to the gray value, select the maximum or minimum points as a candidate extreme points from altogether 80 neighboring voxel points. The candidate extreme points are accurately located in difference of Gaussian scale space, and the low-contrast points and edge response points are eliminated to get the real feature points.

It is necessary for each established feature points to generate the corresponding feature vector, as shown in Fig. 2.2. In three-dimensional space, an area is divided into $16 \times 16 \times 16$ portions taken the feature points as center. And the row and column including feature points do not belong to the area. Then, the area is divided into subregions of $4 \times 4 \times 4$. The gradient direction histogram of the voxel is calculated in subregions. Each subregion becomes a seed point by counting accumulative values in the gradient direction with histogram. The area is divided into $4 \times 4 \times 4$ subregions, that is, a total of 64 seed points, and feature vector is composed of all subregions gradient direction histogram. Finally, a 4096-dimensional feature vector is formed.

2.1.2. Matching feature vector

The correspondence of features points between two images is established by matching generated feature vectors. The Euclidean distance between the feature vector u in the image and all feature vectors in another image is compared. When Euclidean distance between the feature vector v in another image and u is the lowest