Optik 124 (2013) 4266–4273

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

A non-rigid cardiac image registration method based on an optical flow model

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ARTICLE INFO

Article history:
Received 3 July 2012
Accepted 29 December 2012

Keywords:
Non-rigid registration
Medical image
SIFT algorithm
Optical flow model

ABSTRACT

According to non-rigid medical image registration, new method of classification registration is proposed. First, Feature points are extracted based on SIFT (Scale Invariant Feature Transform) from reference images and floating images to match feature points. And the coarse registration is performed using the least square method. Then the precise registration is achieved using the optical flow model algorithm. SIFT algorithm is based on local image features that are with good scale, rotation and illumination invariance. Optical flow algorithm does not extract features and use the image gray information directly, and its registration speed is faster. The both algorithms are complementary. SIFT algorithm is used for improving the convergence speed of optical flow algorithm, and optical flow algorithm makes the registration result more accurate. The experimental results prove that the algorithm can improve the accuracy of the non-rigid medical image registration and enhance the convergence speed. Therefore, the algorithm has some advantages in the image registration.

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1. Introduction

Medical image registration is an important technology in medical image analysis and it is the basis of medical image fusion. The purpose of medical image registration is to find a series of space transforms for a medical image and make it match the corresponding points on another medical image in space or anatomical structure. In the diagnosis process, because some different objective factors (i.e. the different physical mechanisms, the imagining parameter changes and the different imaging device resolution), different modes images show different properties. So there are many limitations if the doctors themselves register two pieces or two groups of different modes images in space, this method has a greater subjectivity and it's inevitable to cause errors.

Especially in the fields of stereotactic radiosurgery, cardiac surgery visualization and so on, the image registration accuracy must be higher than traditional methods, heart and other soft-tissue organs are usually involved. The medical image registration becomes a necessary and difficult task.

In many cases, the characters of deformation are non-rigid and non-linear, even for the head images which are nearly rigid object that cannot simply use the rigid registration. So rigid transformation and affine transformation can't stimulate the local soft-tissue organs deformation efficiently. For some special parts, due to the differences between soft tissue and the air susceptibility, the magnetic field has a larger change that results in heavily geometric distortion. To meet clinical practice needs, most domestic and foreign researchers are interested in the deep study of non-rigid medical image registration algorithms.

Moravec first proposed corner detection operator to realize the stereoscopic vision matching [1], based on which, Harris has improved the Moravec operators [2]. Harris corner operator with scale, rotation invariant is widely introduced to many image registration algorithms. But it is sensitive to illumination changes, scale, viewpoint and the anti-noise capacity is worse [3]. In 2004, Lowe, from Colombia University, proposed a new feature point extraction algorithm—SIFT algorithm [4]. The algorithm can extract the stable feature and has a powerful ability for matching images. It is invariant to scale, illumination, and rotation. And it also immunes to the changes of viewpoint, radioactive, and noise. Therefore this method is successfully used in image registration field. Horn related with 2-D velocity fields and gray scale innovatively, introduced optical flow constraint equation, and achieved the basic algorithm of optical flow computation. Because the displacement field and the velocity field that are from registration and optical flow model are similarity. So, Palos introduced optical flow model to image registration, but these methods are also based on Horn model. Jean-Philipe Thirion proposed "demons-base" algorithm [5] that is a simple flexibility registration method based on the image gray scale information and is similar to the Maxwell's experiment principle in the 19th century. In the algorithm, to judge all pixel points motion direction in registration images is the first step and then elastic registration is achieved moving pixel points [6–8].

In the algorithm of optical flow, when $||\nabla(R(x))||$ is equal to zero, the direction of movement at pixel x can't be decided. Gray level distribution of image are different, and the gray level distribution

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0030-4026/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.ijleo.2012.12.055

of the same anatomical position is also different, so gray difference of image and gray gradient are not enough for image transform, so Demons algorithm can only be used for mono-modality image registration. In order to move the pixel correctly, the improved Demons algorithm used for multi-modality registration is proposed in this article and the algorithm improves mutual information between two images. The implement method is that another force is attached to the former force of image deformation, that is, the floating image is adjusted to match with reference image, mutual information is used for measuring the changes of the two images. When the mutual information gets to the maximum, the two images are registered.

The main registration methods are medical image registration based on image feature and medical image registration based on intensity information. The both methods have defects. The former method needs to segment images to extract the image features and it is hard to preselect feature by artificial control, so the registration speed and the accuracy are not good enough. The later method has to calculate the entire image directly, so the registration time, the speed and robustness are also not satisfied.

With the aim of solving the defects of present registration technology, this article proposes the non-rigid cardiac image classification registration method. The precise registration based on the optical flow algorithm is realized after the coarse registration is finished by SIFT algorithm. Feature point extraction is the basis of medical image registration and its accuracy affects the matching results directly. SIFT algorithm is based on local image features with good scale, rotation and illumination invariant. Optical flow algorithm doesn't need to extract features and it speeds up registration process using image gray information immediately. The both algorithms are complementary. SIFT algorithm is used for improving the convergence speed of optical flow algorithm, and optical flow algorithm makes the registration result more accurate. In the article the interpolation method combines the linear interpolation and the central difference method, and final registration is achieved using multi-resolution strategy.

2. Cardiac motion analysis based on the theory of non-rigid motion

Time series cardiac image is researched in the article, a cardiac image is analyzed to build a cardiac image model that is used to simulate the deformation process. And then the registration results are analyzed. Above all, it is important and necessary to analyze the research objects using the method of motion analysis. During cardiac cycle, the cardiac motion and deformation are complicated. According to Potel's discovery [9], except for global cardiac deformation (such as contraction and expansion), there are also rigid cardiac motion and local cardiac deformation. About 90% ventricular wall motions are away from or close to ventricular systole, which means that contraction and expansion are more important than translation, torsion and rotation. Based on the non-rigid motion analysis theory and Potel's research, the cardiac motion can be divided into global and local motion (Fig. 2.1).

Based on the non-rigid movement theory, cardiac motion analysis is the motion decomposition process .It is also an estimation process from coarse to precise registration and from global to local. The main steps are shown as follows:

(1) Moving reference coordinate system is constructed to calculate the global motion and the cardiac deformation.
(2) Extended super quadrics are fitted to estimate global cardiac deformation in the moving reference coordinate system.
(3) The local cardiac deformation is estimated.

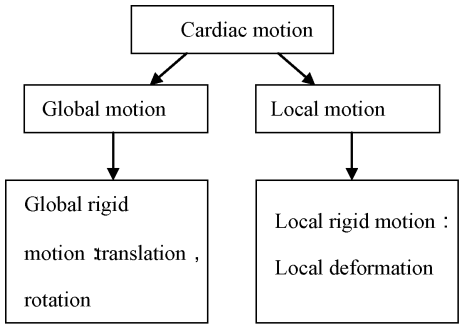

Fig. 2.1. Cardiac motion analysis.

2.1. Global cardiac motion analysis

First, the global rigid cardiac motion is estimated and separated from the global motion during motion decomposition. The local-coordinate system is built, the axis is defined as the cardiac principal axis, and the origin is defined as the systole center. Therefore, global rigid cardiac motion between two moments can be determined according to the changes of the local-coordinate location and the direction [10].

Global cardiac deformation consists of contraction, expand and torsion along with long axis in three orthogonal directions. The global rigid motion compensation is performed before global deformation analysis. The 3-D vessel skeleton points between two moments are fitted into a spatial surface when local-coordinate is concentric. At last, global cardiac deformation is estimated after analysis of the surface deformation.

2.2. Local cardiac motion analysis

Sun Zheng used a 3-D vessel centerline motion estimation method [11] to get the corresponding relation between the vascular skeleton points of two moments (i.e. the displacement of points).

According to the calculated global motion and deformation parameter, the skeleton points at the second movement are recovered to the former position. Without considering the errors, the difference of position between corresponding points is the displacement caused by local motion.

3. SIFT feature vector matching algorithm and coarse registration

3.1. SIFT feature vector generation

Image feature points with rich information are very important to the image local features. It is convenient to be expressed and measured, and it can adapt to the change of light condition, geometrical distortion and occlusion.

The intuitive define of feature point is that the image gray scale change is larger in two directions, such as the corner of outline, the end of segments and so on. Image feature point detection plays an important role in image registration. Not only it can reduce computation greatly, but also reduce the effects of noise. It also has a better adaptability to gray scale transformation, image deformation, occlusion and others. SIFT feature is image local feature. SIFT algorithm is divided into two steps. The first step is to produce SIFT feature vectors and extract feature vectors that is invariant to rotation, scale and illumination from reference images and floating images. The second step is to realize the feature vectors matching [12,13]. The registration images are normalized before generation of SIFT feature vectors. The image size is expanded to double and the noise is eliminated by prefiltering. At last, the bottom of Gauss

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