Application of Non-rigid Registration of MR Images Based on GMI-Demons Algorithm in Prostate

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Abstract

Accurate registration of medical images has important significance in the process of medical diagnosis. In this paper, global rigid registration was firstly used to sequence images of prostate DWI, so as to minimize the errors caused by beam position. Then, use combined gradient mutual information based Demons algorithm (GMI-Demons) to achieve local deformable registration. By the analysis and comparison of registration results, maximization of mutual information values indicates that image accuracy after GMI-Demons-based registration is higher than original Demons-based registration. The quantitative analysis shows that the registration strategy proposed in this paper can produce better registration results rapidly, which has research significance in clinical application.

Keywords

Non-rigid registration; Sequence images of prostate DWI; Demons algorithm; Image gradients

1. Introduction

Medical image registration is an important and the fundamental research issue in the area of medical image processing; it is the basis of the research of medical image fusion, reconstruction, matching, etc. The so-called image registration is that to find geometric transformation of two images which, in different time and different conditions, makes corresponding points on the space of two original images reach agreement after transformation [1]. Because the long time of imaging, drift of soft tissues caused by breath and involuntary movement. In order to obtain the lesion location accurately, the registration of sequence images of prostate DWI is necessary. Due to the common non-rigid characteristics of human organs and tissues, we need non- rigid registration. Non-rigid image registration is more suitable for registration of human tissues under the conditions of compression and movement [2].

With the aging population and the improvement of medical standards, prostate disease has become one of the important diseases which threats older men. The gold standard of check is biopsy puncture. However, biopsy is invasive and causes varying degrees of damage to the body. In recent years, MRI, as a non-invasive approach, a is applied to prostate diagnosis, biopsy guiding, cancerous tissue measuring and positioning, postoperative follow-up, and other aspects. It significantly improves the identification of prostate cancer tumors [3].

Demons algorithm [4] is a non-parametric non-rigid registration based on optical flow field, it has been widely used with high running speed while guarantees the good effect of registration. Demons algorithm, was first proposed by Thirion and a kind of non-linear registration based on gray level. it utilizes the reference image gradient information to drive the floating image transform. The literature [1] combines with and also improved Demons algorithm (GMI-Demons) based on gradient mutual information. Increase the force of the gradient mutual information between two images as another factor to image deformation maximizes gradient mutual information at the same time with the registration of two images. It is proved that the improved algorithm has higher performance than the traditional Demons algorithm, and registration of sequence images of prostate DWI can be realized.

In this paper, we implemented and verified a non-rigid image registration method with application in sequence images of prostate DWI. Global rigid registration was firstly used to images. And, then, using GMI-Demons based on gradient mutual information drives the image deformation, to achieve local registration between two images and also evaluates the accuracy of registration using mutual information. By analyzing, the scheme of non-rigid registration we proposed is effective with application in sequence images of prostate DWI and has greater clinical significance.

2. Method

2.1 Traditional Demons algorithm

Traditional Demons algorithm was proposed by Thirion, one method of registration based on the theory of optical flow. Image matching is regarded as a diffusion process from floating image to reference image. Diffusion rate is determined by the gradient information of reference image [5]. The basic hypothesis of optical flow is to consider that the intensity of a moving object is constant with time, which gives, for small displacements, the optical flow equation

$$v \bullet \nabla r = f - r \tag{1}$$

Which r is reference image and f is floating image. The constraint is not sufficient to define the velocity v, further leads to Equation (2)

$$v = \frac{f - r}{\|\nabla r\|^2} \bullet \nabla r \tag{2}$$

This equation is unstable when $\|\nabla r\| \to 0$, leading to infinite values for v, a solution is adding a weight in denominator, which gives Equation (3)

$$v = \frac{(f - r)\nabla r}{\|\nabla r\|^2 + (f - r)^2} \tag{3}$$

Ensure that the topology of the images, usually use Gaussian filter to smooth the displacement, gives diffusing models

$$v_{n+1} = G_\sigma \otimes \left(v_n + \frac{(f - r)\nabla r}{\|\nabla r\|^2 + \alpha^2 (f - r)^2} \right) \tag{4}$$

Which G_σ is Gaussian filter and σ is elastic coefficient.

2.2 Incorporating and improving gradient information

Gradient to some extent reflects the profile information of the image, which are locations of high information value [6]. The gradient is computed on a certain spatial scale and the mutual information just lack of this kind of space information. This non-rigid matching algorithm combining gradient information and mutual information will be conducive to utilize gray information and spatial information sufficiently. The improved diffusing models becomes

$$v_{n+1} = G_\sigma \otimes \left(v_n + \frac{(f - r)\nabla r}{\|\nabla r\|^2 + \alpha^2 (f - r)^2} + \beta Max\left(I_{GMI}(v_n)\right) \right) \tag{5}$$

The gradient term is based not only on the magnitude of the gradients, but also on the orientation of the gradients.

Orientation of the gradients

Setting a threshold for the gradient magnitude T_h

$$T_h = \frac{1}{2} \sqrt{\sum_{x=1}^{M} \sum_{y=1}^{N} \frac{|\nabla r|^2}{M \times N}} \tag{6}$$

M and N are the size of images. Set Orientation to 0 when gradient magnitude is less than T_h. The gradients vectors is defined by

$$\alpha_{r,f} = \begin{cases} \arccos \dfrac{\nabla r \bullet \nabla f}{|\nabla r| \bullet |\nabla f|}, |\nabla r| > T_h \\ 0, |\nabla r| < T_h \end{cases} \tag{7}$$

Use the following weighting function ω, which favors both very small angles and angles that are approximately equal to π.

$$\omega(\alpha_{r,f}) = \frac{\cos(2\alpha)+1}{2} \tag{8}$$

Magnitude of the gradients

Between two images, the gradient magnitude of corresponding points more closer, the more similar pixel values. Therefore measure the similarity of corresponding pixel points through the ratio corresponding point to gradient magnitude defined by

$$g_{r,f} = \begin{cases} \dfrac{\min(|\nabla r|, |\nabla f|)}{\max(|\nabla r|, |\nabla f|)}, \max(|\nabla r|, |\nabla f|) \neq 0 \\ 1, \max(|\nabla r|, |\nabla f|) = 0 \end{cases} \tag{9}$$

The new gradient information becomes

$$I_G(r, f) = \sum_{r,f \in R \cap F} \omega(\alpha_{r,f}) \bullet g_{r,f} \tag{10}$$

New registration measure combination of mutual information and normalized gradient information becomes

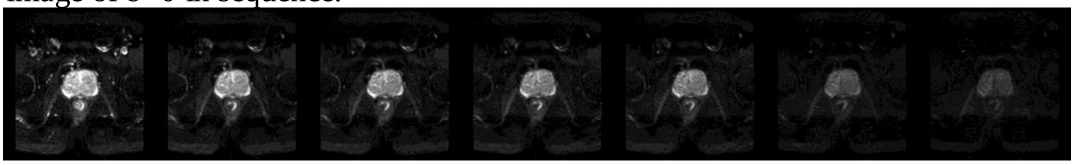
$$I_{GMI} = N_{IG}(r, f) \bullet N_{MI}(r, f) \tag{11}$$

In the estimation process, using Parzen window method, $g(x, y; \mu)$ is deformation, parameter $\mu = (\mu_1, \mu_2, \cdots \mu_N)$,get the diffusing models

$$v = \frac{\left(\dfrac{\partial I_{GMI}}{\partial_{\mu_1}}, \dfrac{\partial I_{GMI}}{\partial_{\mu_2}}, \cdots \dfrac{\partial I_{GMI}}{\partial_{\mu_N}} \right)}{\sqrt{\sum_{i=1}^{N} \left| \dfrac{\partial I_{GMI}}{\partial_{\mu_i}} \right|^2}} \tag{12}$$

2.3 Registration process

Sequence images of prostate DWI sample contains seven images shown in figure 1. The main factor of DWI imaging is diffusion sensitive factor, which is b value. With the increase of *b* value (*b*=0, 50, 100, 150, 200, 500, 800 mm^2/s) brings prostate position drift, the image gray becomes more and more low. Because the image is closest to the true shape when *b*=0, other images are required to register with the image of *b*=0 in sequence.



(1) (2) (3) (4) (5) (6) (7)

Fig.1 sequence images of prostate DWI (1)b=0; (2)b=50; (3)b=100; (4)b=150; (5)b=200; (6)b=500; (7)b=800

Step 1: Apply rigid registration to original images to get a starting spatial transformation, so as to initialize non-rigid registration transformation fiel

Step 2: Use GMI-Demons algorithm to perform image-to-image matching. After iterating for *N* times, the position x_i^n of the pixel of floating image *i* is $x_i^n = x_i^{n-1} + v_i^{n-1}$, which is calculated by the equation (12)

Step 3: If the mutual information variation between the two images is less than a preset threshold, iteration is convergence, go to the next resolution, to Step 4； Otherwise go to the next iteration *n + 1*.

Step 4: At the end of iterations, use the diffusion rate *v* obtained before to act on the floating image, and to achieve the registration of sequence images of prostate DWI.

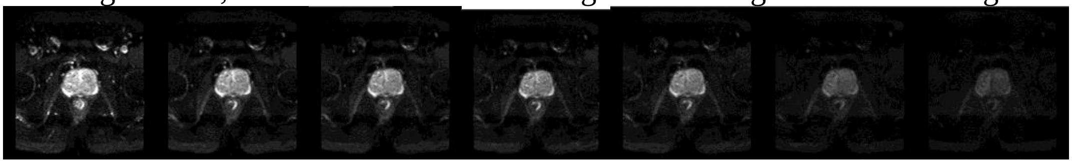
2.4 Similarity measure

Image correspondence is the same position of the human body. So when the spatial information of the two images is exactly the same, image gray mutual information should be the largest. Using the measure of maximum mutual information to evaluate the results of prostate images registration.

$$I(R,F) = \sum_{r,f} P_{R,F}(r,f) \log \frac{P_{R,F}(r,f)}{P_R(r) \cdot P_F(f)} \tag{13}$$

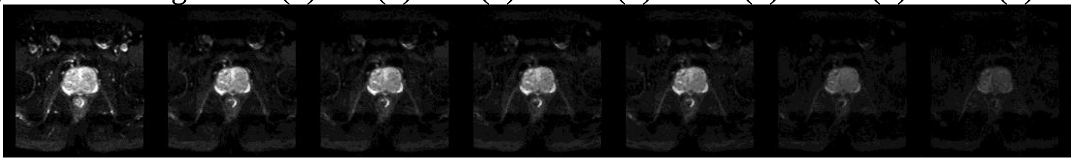
3. Results

In order to verify the accuracy of the registration scheme in this paper, contrast experiments are carried out in two groups to registration prostate images:(1) Demons algorithm; (2) GMI-Demons algorithm. The Demons algorithm and the GMI-Demons algorithm are applied to sequence images of prostate DWI registration, and results are shown in Figure 2 and Figure 3 as following:



(1) (2) (3) (4) (5) (6) (7)

Fig.2 Demons algorithm (1)b=0 (2)b=50(3) b=100 (4)b=150 (5)b=200 (6)b=500 (7)b=800



(1) (2) (3) (4) (5) (6) (7)

Fig.3GMI-Demons algorithm (1)b=0 (2)b=50 (3)b=100 (4)b=150(5)b=200 (6)b=500 (7)b=800

In order to further verify the effectiveness of the algorithm clearly, Table 1 shows the MI values. GMI-Demons algorithm has double excellence between traditional Demons algorithm and gradient mutual information. Through this method, image registration is completed and the accuracy of image registration is improved.

Tab. 1 MI of sequence images of prostate DWI

	Before registration	Rigid registration	Demons algorithm	GMI-Demons algorithm
b=50	2.0197	2.0255	2.4604	2.7742
b=100	1.8901	1.9289	2.3324	2.6446
b=150	1.7785	1.8317	2.2080	2.5223
b=200	1.7730	1.8254	2.1628	2.4422
b=500	1.4754	1.5326	1.7181	1.9463
b=800	1.2576	1.3054	1.4445	1.6690

It can be clearly seen from Figure 3, the MI values based on GMI-Demons algorithm are much higher than traditional Demons and rigid registration algorithm.

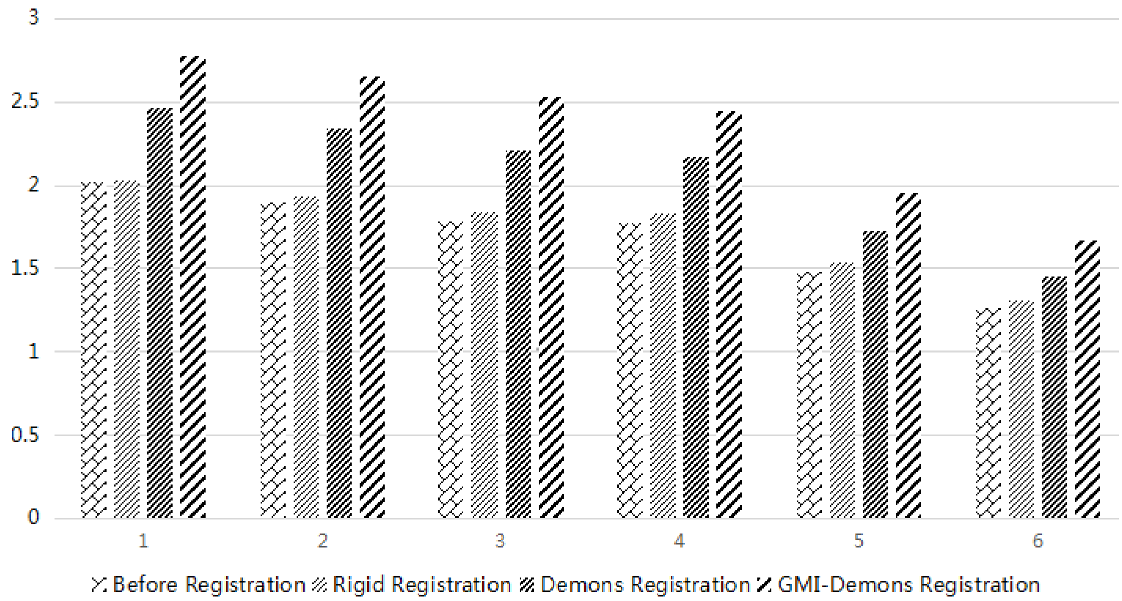


Fig. 3 Mutual information histogram

4. Conclusion

We propose the registration scheme for sequence images of prostate DWI which is incorporated with spatial information. Combine either standard or normalized mutual information with gradient information. The results presented in this study indicate that GMI-Demons algorithm outperforms both the Demons algorithm and rigid registration. Based on the analysis of the registration results, the effectiveness of the proposed algorithm program for sequence images of prostate DWI is verified and the matching degree between images is improved.

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