Hierarchical and successive approximate registration of the non-rigid medical image based on thin-plate splines

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Abstract. The hierarchical and successive approximate registration method of non-rigid medical image based on the thin-plate splines is proposed in the paper. There are two major novelties in the proposed method. First, the hierarchical registration based on Wavelet transform is used. The approximate image of Wavelet transform is selected as the registered object. Second, the successive approximation registration method is used to accomplish the non-rigid medical images registration, i.e. the local regions of the couple images are registered roughly based on the thin-plate splines, then, the current rough registration result is selected as the object to be registered in the following registration procedure. Experiments show that the proposed method is effective in the registration process of the non-rigid medical images.

1 Introduction
The registration of medical image is a vital component in the application fields of the clinical medicine. The comparison of medical images of different patients can help the clinical doctor give the detailed and accurate treatment plan. The medical image registration methods mainly include rigid and non-rigid registration. More and more methods of registration focus on the non-rigid registration due to the deformation of the medical image is non-rigid usually. The non-rigid registration methods of medical image mainly include two works, i.e. finding a number of corresponding control points in the couple images to be registered, and then, exploring an optimum transformation function to accomplish the match between all points in the couple images. The non-rigid registration methods can be mainly classed into registration based on parameters and models. Thin-Plate Spline(TPS) and other spline functions are the major transformation functions used in the deformable medical images registration based on parameters. And TPS has been widely used function since Bookstein used TPS in the image’s elastic registration[1]. Likar[2] proposed a hierarchical approach to elastic registration based on mutual information and TPS. Rohr proposed a series elastic medical image registration methods based on approximating thin-plate splines[3-5]. In addition, there are a lot of researches about registration using TPS[6-14] for that TPS can be used in the interpolation of the deformable image effectively. A hierarchical and successive approximate registration method for the medical images based on TPS is proposed in the paper.

2 Hierarchical and Successive Approximate Registration Based on TPS
The thin-plate splines were proposed by Duchon[15] and Meinguet[16], which was widely used in the non-rigid image registration.

2.1 Thin-Plate Spline
Let \( p_i \) and \( q_i \) denote the landmarks of the couple images of dimension \( d, \ i = 1, \ldots, n \). Then the transform \( u \) should be found to accomplish the transform from \( p_i \) to \( q_i \), i.e. \( q_i = u(p_i) \). And \( u \) should minimize a given functional

\[
J : \mathbb{R}^d \rightarrow \mathbb{R}^d :
\]

\[
J^d(u) = \sum_{k=1}^{d} J^d_k(u_k)
\]

where every \( u_k \) is one component of \( u \), \( m \) is the derivative order of every \( u_k \). And the single functionals read as

\[
J^d_k(u_k) = \sum_{\alpha_1, \ldots, \alpha_d} \frac{m!}{\alpha_1! \cdots \alpha_d!} \int \cdots \int \frac{\partial^m u_k}{\partial x_1^{\alpha_1} \cdots \partial x_d^{\alpha_d}} \, dx
\]

where \( \alpha_i \) is positive integer, \( x_i \) is the \( i \) th component of \( x \), \( i = 1, \ldots, d \). It’s analytic form solution of functional in (2) is

\[
u_k(x) = \sum_{i=1}^{d} a_i \phi_i(x) + \sum_{i=1}^{d} b_i U(x, p_i)
\]

where \( \phi(x) = 1 \), \( \phi(x) = x \) and \( \phi(x) = y \) as dimension \( d = 2 \), \( U(x, p_i) \) is the basis function of interpolation, and it’s analytic form corresponding to \( d = 2 \) is:

\[
U(x, p_i) = \begin{cases} 
|x - p_i| \ln |x - p_i|, & |x - p_i| \neq 0 \\
0, & |x - p_i| = 0 
\end{cases}
\]

The analytic solution of (3) can be obtained by solving the following linear equations:

\[
\begin{bmatrix} Kw + Pa = v \\
P^TW = 0 \end{bmatrix}
\]

where \( K_y = U(p, p_i) \), \( P_y = \phi_i(p_i) \), and \( v \) is the column vector of one component of the coordinates of the target image’s control points \( q_i \). What showed in Fig. 1 are the example graphics of thin-plate spline.

![Figure 1: Grid deforming by using thin-plate spline](image)

(a) Initial grid \quad (b) Deformed grid

2.2 Extraction of the Target Region

The tumor will cause the local tissue distorted in the clinical. And the shape of the corresponding region usually is the approximate ellipse. The edge of the image can be extracted by Canny operator before obtaining the points in the warped region’s edge. After this, one base point can be selected at ellipse inner as the initial point to search the edge point of the warped region. A straight line passing the base point is scribed at first, it will intersect with the edge of the region and generates two edge points. All the edge points can be obtained by parallel moving the straight line.
2.3 Extraction of Control Points
The control points used in TPS are extracted at first. The details are that the radial lines started from the warping region center will intersect with the edge line of the deformed region. These intersection points are selected as control points in the procedure of registration. Let \((x_c, y_c)\) denote the center coordinate of the local warping region. Then radial lines can be drew from \((x_c, y_c)\), which will intersect with the edge line of the warping region. Let \(\{p_i, i = 1, \ldots, n\}\) be the intersection points, where \(n\) is the number of radial lines. Due to the registration is accomplished in the local ellipse region, the half lines will also intersect with the boundary line of the local region. Let \(\{bp_i, i = 1, \ldots, n\}\) denote the intersection points of the radial lines and the boundary line, then \(\{p_i\}\) together with \(\{bp_i\}\) are selected as the control points used in TPS. Fig. 3 shows the selection of control points.

2.4 Hierarchical and Successive Approximate Registration
The local region is decomposed by Wavelet transform after the warped region was extracted. The registration is started from the coarse scale to fine scale of wavelet transform. In order to avoid the error and reduce calculation in every level’s registration, the image in low-frequency is selected as the object of registration. And the different amount of control points are selected in the different level of registration. The method of control points’ selection used in thin-plate spline is as follows. Let \(\theta_0\) be the angle of the first radial drawn out from the center of region’s edge, the incremental angle is \(\Delta \theta\), then the angle of the radial line related to \(p_i\) and \(bp_i\) is

\[
g(\theta) = \theta_0 + (i - 1)\Delta \theta
\]

Due to the method of successive approximation is used in the registration procedure, the control points are changed in the every time of the approximation, the angle of the radial corresponding to the new control point of the \(k\)th approximation is

\[
g(\theta, \alpha) = (k - 1)\alpha + \theta_0 + (i - 1)\Delta \theta
\]

where \(\alpha\) is the changed angle of the first half line in the every approximation, and \(k \in [1, N]\). The calculation of \(N\) is as follows.
Thus, the different sets of the control points can be used in every registration procedure. This can help to obtain the more accurate registration result. In order to obtain the most accurate result in the whole registration procedure, Euclidean distance of the edge points of the target image and the interpolation image is selected as the similar measure for that the local warping region is only considered in the registration. The registration result corresponding to the minimum of the similar measure is the optimal result. In addition, after the registration of low-frequency sub-image, the initial images are selected as registration’s objects more times.

3 Experiments

All the images used in the experiments are all consist of 256×256 and 8 bits grey-scale medical images. Images showed in Fig.4 are the experiment results, where (a) is the source images, (b) is the target images, (c) is the registered image. \( \theta_0 = 0, \alpha = \pi/12 \). The Euclidean distance of all pixels in the edge of the couple images is selected as the registration error. The value of registration error of registered result is 3.32.

3 Conclusion

A novel non-rigid registration method of the medical image based on local region is proposed in the paper. In the registration procedure, the two major steps are the hierarchical registration and successive approximate registration based on TPS. The experiments demonstrated the effect and accuracy of the proposed method.

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