A Projection-Based Image Registration Algorithm and Its Application

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Summary: Proposed is a projection-based image registration technique where, by rearranging the projections of characteristic images, the image registration is implemented with two independent steps - rotation and translation, to perform the two-dimensional or three-dimensional rigid-body image registration addressing the head motion problem in functional magnetic resonance imaging (fMRI). For a 2D problem, the approach is based on a one-dimensional projection of a segmented two-dimensional characteristic image, in which the translation and rotation parameters are obtained with a one-dimensional cross-correlation-based estimator. This is then used to compute the cross-correlation between the projection of an image and a registration table that is created by rearranged projections of a selected two-dimensional image with various rotation angles. In this approach, the translation registration table may be created by rearranged projections of sub-voxel level two-dimensional images with various sub-voxel level parameters, and so it may be applied into a sub-voxel registration. Such an approach replaced the general multi-dimensional optimization procedure with a linear projection calculation and a finite cross-correlation with a registration table, thus the amount of computation is considerably reduced. The performance of this method was confirmed by simulation study different SNRs and applications to 2D and 3D actual functional MRI images.

Key words: Image registration; Projection; Sub-voxel; Registration table.

Introduction

Image registration is widely used in medicine such as multi-modality fusion, image segmentation, deformable atlas registration, functional brain mapping, image-guided surgery (Ardekani et al. 2000; Hsu et al. 2001) and characterization of normal versus abnormal anatomical shape and variation. The fundamental assumption commonly made in these applications is that image registration can be used to define a meaningful correspondence mapping between anatomical images collected from imaging devices such as computed tomography (CT), magnetic resonance imaging (MRI), cryosectioning, functional MRI (fMRI), etc. (Biswal et al. 1997; Speck et al. 2001).

Commonly used registration techniques include Fourier transform (Eddy et al. 1996), mutual information (Kim et al. 1999), and cross-correlation method (Barnea et al. 1996). Recently, a projection-based registration technique was reported which is based on the concept of integral projection that is computationally efficient and can achieve improved performance over the traditional 2-D cross-correlation-based techniques in the presence of both fixed-pattern and temporal noises (Cain et al. 2001). The basis of this technique is that the linear phase associated with simple translations is encoded on the Fourier axes (Chrisrens et al. 2001).

In this paper, we present a projection-based technique which is different from Cain’s projection-based algorithm (Cain et al. 2001) in that the images are firstly segmented and the projections are rearranged so that the registration can be implemented with independent rotation and translation registrations, thus extending the original translation-only registration to both translation and rotation registration. This paper is organized as follows. In the appendix, the formulations for our 2D and 3D projection-based registrations are presented; in the main body of this paper, details are presented for the 2D situation. In Section 2 the method is presented in detail. In Section 3, 2D computer simulations are conducted. Section 4 gives the implementation of fMRI images pro-
cesses and the results before and after 2D and 3D registrations. The conclusion and discussion are in section 5.

**Methods**

Our method includes the following five aspects, image segmentation, projection and rearrangement, rotation registration, translation registration and sub-voxel registration. They are illustrated in the following 2D case.

**Image Segmentation**

The general principle of projection-based estimator is presented in the form of a continuous function for original image registration (Davatzikos et al. 2001). However, original image registration algorithms are prone to be inaccurate when there are residual variations due to partial volume effects or biological variation. In particular, magnetic susceptibility artifacts resulting in remarkable signal intensity variance and motion artifact in fMRI datasets are difficult to eliminate, which may mislead the estimation of motion parameters and result in a large computation burden (Elsen et al. 1994; Hsu et al. 2001). To reduce computation and avoid unnecessary disturbance from the above noted less important features such as those related with the background gray information, it is necessary to implement image segmentation. Then, the parameters for an image registration can be obtained by registering the characteristic images instead of original image registration. Therefore, for time serial images, based on a selected reference image, the registration procedure includes three steps: first, find the matched parts respectively in the image to be registered and in the reference image, which is named image segmentation (Maas et al. 1994); second, compare the two matched parts of the images to get parameters for the registration; finally make image registration according to the parameters (Kassam et al. 1996; Stone et al. 2001). In general, implementation of rotation and translation registrations, no matter on the original images or on the segmented images, is an optimization of three parameters. Based on the projections of the segmented images we introduce a rearrange operation of the projections that allow the rotation and translation registrations to be divided into two independent steps that further simplify registration optimization.

Suppose the reference image \( F(x,y) \) and the non-registered image \( G(x,y) \) illustrated in figure 1a and b are two \( m \times n \) matrices where the values of \( x,y \) variables respectively are in the range \([1,m]\) and \([1,n]\), \( G(x,y) \) and \( F(x,y) \) denote gray-scale values at \( (x,y) \). For the MRI head motion problem, images a and b in figure 1 are assumed as the measured brain images of the same brain slice at different time points. In figure 1, image a is used as the reference image, and image b is used as a non-registered image due to the head movement of the subject.

For the segmentation, we assume that a threshold-segmented image may be used as the represented characteristic image. Figure 2 shows the threshold-segmented images of those in figure 1, where the value larger than threshold is set to be 1, and the others are set to be 0 (zero-one segment). By using such characteristic images, we reduced the computation load and also eliminated the effect of instantaneous noise change. The threshold for the brain image is generally chosen by experience, which ensures that the characteristic image \( f(x,y) \) can represent the original image \( F(x,y) \).

**Projections and Rearrangement**

If the characteristic images are good approximation representations of the original image, the registration of the characteristic images is approximately equivalent to the registration of the original image. Here we assume the image intensities are stable over time and the approximation is reasonable because the head movement is generally limited in a finite range.

Now, we need to find the registration parameters of rotation angle and translation values. In general, it is a three-dimensional non-linear optimization problem. Here we propose a new efficient procedure with a projection operation to get the registration parameters shown as below.