A Region-Based Mutual Information Method for Image Registration

Xiuquan Ji, Hao Pan, Zhi-Pei Liang
Department of Electrical and Computer Engineering,
University of Illinois at Urbana-Champaign, Urbana, IL 61801, U.S.A.

Introduction
With the increasing use of MR images obtained from different pulse sequences and/or at different times for diagnostic and research purposes, developing an accurate method for automatic image registration has become an important research problem. A main challenge lies in developing an effective image similarity metric which can handle images with large contrast differences and variable resolutions. Many methods have been proposed to address this issue over the last decade [1-4]. This paper presents a region-based mutual information (RMI) method which unifies two recent methods: the mutual information method [1] and the region matching method [2].

The Proposed Method
The basic idea of the proposed method is to make use of both the “statistical” distribution of pixel intensity values between two images and their structural information to guide the registration process. Pixel-based mutual information (MI) [1] is a statistically consistent method to use intensity information for image registration. The region matching method [2] effectively uses structural information to align images with large contrast differences. Taking advantage of the desirable features of these two methods, the proposed method is more effective and reliable. Specifically, given two images $I_1$ and $I_2$ to register, we first segment each of them into a set of “homogeneous” regions, denoted by $\{R_1(n)\}$ and $\{R_2(m)\}$, using the multiscale segmentation algorithm [2]. Second, two label fields $L_1$ and $L_2$ are created such that

$$L_1(\vec{r}) = n, \quad \vec{r} \in R_1(n), \quad \text{and} \quad L_2(\vec{r}) = m, \quad \vec{r} \in R_2(m).$$

The mutual information between $(I_1, L_1)$ and $(I_2, L_2)$ is given by

$$I(I_1, L_1; I_2, L_2) = \sum_{i_1 \in I_1} \sum_{l_1 \in L_1} \sum_{i_2 \in I_2} \sum_{l_2 \in L_2} \sum_{l_1, l_2} \log \frac{p(i_1, l_1, i_2, l_2)}{p(i_1, l_1) p(l_2, i_2)},$$

where the probabilities are estimated by normalizing the joint histogram as in [1, 3]. In principle, $I(I_1, L_1; I_2, L_2)$ takes into account all the available information and should be most effective. However, under some practical situations, the following “simplified” versions are more desirable.

a) Mutual information between $L_1$ and $L_2$:

$$I(L_1, L_2) = \sum_{i_1 \in L_1} \sum_{i_2 \in L_2} p(L_1, L_2(i_1, i_2)) \log \frac{p(L_1, L_2(i_1, i_2))}{p(L_1(i_1)) p(L_2(i_2))},$$

b) Mutual information between $I_1$ and $L_2$ or $L_1$ and $I_2$,

$$I(L_1, L_2) = \sum_{i_1 \in L_1} \sum_{i_2 \in L_2} p(L_1, L_2(i_1, i_2)) \log \frac{p(L_1, L_2(i_1, i_2))}{p(L_1(i_1)) p(L_2(i_2))}.$$

$I(L_1, L_2)$ is most useful when $\{R_1(n)\}$ and $\{R_2(n)\}$ are well defined. $I(I_1, L_2)$ or $I(L_1, I_2)$ is useful if $I_1$ and $I_2$ have different resolutions because the region label field for the low-resolution image may not be well defined and should not be used.

With the above metric, the registration parameters are determined by maximizing $I(.)$. This entails solving an optimization problem. The algorithm used in the pixel-based MI [1] is adopted here for interpolation and optimization purposes.

Results and Discussion
The proposed registration criterion has been tested using real MR images. Our study has shown that the proposed metric is rather robust with respect to contrast and resolution differences of the images to be registered. A typical set of results is shown in Fig. 1. Figures 1a-b show two $I_1$-weighted spin-echo images (with $TR = 200$ and $1500$ ms, respectively). Figures 1c-d show the closed regions extracted from them. Figure 1e shows the RMI values for different rotation angles. As can be seen, the metric is a rather smooth “unimodal” function of the registration parameter (in this case, the rotation angle), whose peak location accurately determines the relative position of the two images. We have found that in many cases RMI surface is smoother and exhibits fewer local minima than the corresponding MI surface.

Conclusion
An image registration method based on a regional mutual information criterion has been presented. Experimental results have shown it can handle images with large contrast differences and variable resolution. The technique should prove useful for a number of applications including functional brain mapping and multimodality image registration.

Acknowledgments
This work was partially supported by the following research grants: JSEP-N000-14-96-0129, NSF-BES-95-02121, NSF-MIP-94-10463, NIH-R01-CA51430 and NIH-P41-RR05964-06.

References