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Biomedical Image Registration

Third International Workshop, WBIR 2006
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Preface

The Third International Workshop on Biomedical Image Registration (WBIR) was held July 9-11, 2006, at Utrecht University, Utrecht, The Netherlands. Following the success of the first workshop (WBIR 1999), held in Bled, Slovenia, and the second workshop (WBIR 2003), held in Philadelphia, Pennsylvania, this meeting (WBIR 2006) aimed to once again gather leading researchers in the area of biomedical image registration so as to present and discuss recent developments in the field.

In modern medicine and biology, a valuable method of gathering knowledge about healthy and diseased organs, tissues, and cells is the integration of complementary information from volumetric images of these objects. Such information may be obtained by different imaging modalities, different image acquisition setups, different object preparation procedures, or by sequential image acquisition in follow-up studies or in dynamic imaging. A necessary pre-processing step for the integration of image information is image registration by which images, containing complementary information, are brought into the best possible spatial correspondence with respect to each other. Enabling combination and quantification of information about location, form and function, image registration is nowadays finding increasing use in diagnosis, treatment planning, and surgical guidance.

This year's workshop consisted of 20 oral presentations with ample time for discussions, 18 poster presentations and 2 tutorials: one addressing techniques and applications and the other numerical methods for image registration. We were delighted to welcome the participants to Utrecht and hope they found the meeting an interesting, fruitful, enjoyable and stimulating experience. For the readers unable to attend the workshop, we hope that you find these proceedings a valuable record of the scientific programme.

We would like to thank everyone who contributed to the success of this workshop: the authors for their excellent contributions, the members of the Programme Committee for their review work, promotion of the workshop and general support, the tutorial speakers for their outstanding educational contributions, the local organization staff for their precious time and diligent efforts, Philips Medical Systems for kind and generous financial support, and all the attendees for their active participation in the formal and informal discussions.

July 2006

Josien P. W. Pluim
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Medical Image Registration Based on BSP and Quad-Tree Partitioning

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Abstract. This paper presents a study of image simplification techniques as a first stage to define a multiresolution registration framework. We propose here a new approach for image registration based on the partitioning of the source images in binary-space (BSP) and quad-tree structures. These partitioned images have been obtained with a maximum mutual information gain algorithm. Multimodal registration experiments with downsampled, BSP and quadtree partitioned images show an outstanding accuracy and robustness by using BSP images, since the grid effects are drastically reduced. The obtained results indicate that BSP partitioning can provide a suitable framework for multiresolution registration.

1 Introduction

Multimodal image registration plays an increasingly important role in medical imaging. Its objective is to find a transformation that maps two or more images, acquired using different imaging modalities, by optimizing a certain similarity measure. Among the different similarity measures that have been proposed, mutual information (MI)[2, 9] and normalized mutual information (NMI)[6] are the most commonly used since they produce satisfactory results in terms of accuracy, robustness and reliability. However, MI-based methods are very sensitive to implementation decisions, such as interpolation and optimization methods, and multiresolution strategies [4]. The latter allow us to reduce the computational cost by means of a coarse-to-fine hierarchical representation of the images. Crucial to building these hierarchies is the selection of the image simplification strategy.

The main objective of this paper is to analyze the behavior of the registration process when the source images are simplified in BSP and quad-tree structures, obtained with a maximum MI gain algorithm [5]. We will see that multimodal registration experiments based on BSP partitioned images show a remarkable accuracy and robustness, reducing substantially the grid effects compared with both regular downsampled and quad-tree images. Since experimental results demonstrate the good performance using these simplification strategies, we suggest they are an ideal strategy for defining a multiresolution framework. Such a framework can be used not only for registration purposes but also for image processing or transmission in telemedicine environments.

J.P.W. Pluim, B. Likar, and F.A. Gerritsen (Eds.): WBIR 2006, LNCS 4057, pp. 1–8, 2006.

This paper is organized as follows. In Section 2, we briefly describe image registration and partitioning techniques using MI maximization. In Section 3, a new image registration framework based on partitioned images is presented. In Section 4, multimodal registration experiments show the suitability of the presented approach. Finally, our conclusions are given in Section 5.

2 Previous Work

In this section we review the MI definition [1] and its application to image registration [2, 9, 4, 7] and partitioning [5].

Mutual Information. Given two discrete random variables, X and Y, with values in the sets $\mathcal{X} = \{x_1, \ldots, x_n\}$ and $\mathcal{Y} = \{y_1, \ldots, y_m\}$, respectively, the MI between X and Y is defined as

$$I(X,Y) = \sum_{i=1}^{n} \sum_{j=1}^{m} p_{ij} \log \frac{p_{ij}}{p_i q_j} \quad (1)$$

where $n = |\mathcal{X}|$, $m = |\mathcal{Y}|$, $p_i = Pr[X = x_i]$ and $q_j = Pr[Y = y_j]$ are the marginal probabilities and $p_{ij} = Pr[X = x_i, Y = y_j]$ is the joint probability. $I(X,Y)$ is a measure of the shared information between X and Y. It can also be expressed as $I(X,Y) = H(X) - H(X|Y) = H(Y) - H(Y|X)$, where $H(X)$ and $H(Y)$ are the marginal entropies, and $H(X|Y)$ and $H(Y|X)$ the conditional entropies [1].

A fundamental property of MI is the *data processing inequality* which can be expressed in the following way: if $X \to Y \to Z$ is a Markov chain, then

$$I(X,Y) \geq I(X,Z). \quad (2)$$

This result demonstrates that no processing of Y, deterministic or random, can increase the information that Y contains about X [1].

MI-based Image Registration. The most successful automatic image registration methods are based on MI, which is a measure of the dependence between two images. The registration of two images is represented by an information channel $X \to Y$, where the random variables X and Y represent the images. Their marginal probability distributions, $\{p_i\}$ and $\{q_j\}$, and the joint probability distribution, $\{p_{ij}\}$, are obtained by simple normalization of the marginal and joint intensity histograms of the overlapping areas of both images [2]. The registration method based on the maximization of MI, almost simultaneously introduced by Maes et al. [2] and Viola et al. [9], is based on the conjecture that the correct registration corresponds to the maximum MI between the overlapping areas of the two images. Later, Studholme et al. [6] proposed a normalization of MI defined by

$$NMI(X,Y) = \frac{H(X) + H(Y)}{H(X,Y)} = 1 + \frac{I(X,Y)}{H(X,Y)}, \quad (3)$$

which is more robust than MI, due to its greater independence of the overlap area.

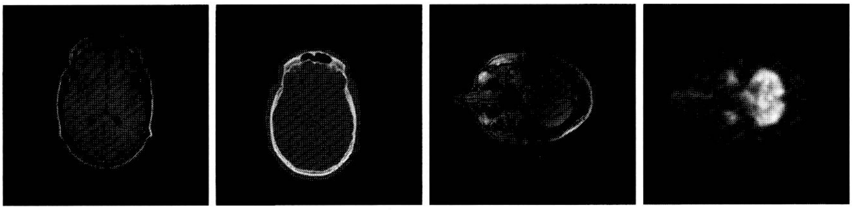
The behavior of the MI-based method depends on the implementation decisions. Thus, for instance, it is especially sensitive to the interpolator and optimizator chosen or the binning and multiresolution strategies [4]. Generally the grid points of the transformed image do not coincide with the grid points of the reference image. Thus, the selection of an interpolator is required. Although there are different interpolators, all of them introduce artifacts due to the error patterns caused by the grid regularity [7]. On the other hand, the simple computation of an MI-based similarity measure by sampling the images on a regular grid leads to undesired artifacts, called *grid effects* [8].

MI-Based Partitioning Algorithm. An MI-based algorithm was presented by Rigau et al. [5] to partition an image. Given an image with N pixels and an intensity histogram with n_i pixels in bin i, a discrete information channel $X \rightarrow Y$ is defined, where X represents the bins of the histogram, with marginal probability distribution $\{p_i\} = \{\frac{n_i}{N}\}$, and Y the image partitioned into pixels, with uniform distribution $\{q_j\} = \{\frac{1}{N}\}$. The conditional probability distribution $\{p_{j|i}\}$ of this channel is defined as the transition probability from bin i of the histogram to pixel j of the image, and vice versa for $\{p_{i|j}\}$. This channel fulfills that $I(X,Y) = H(X)$ since, knowing the output (pixel), there is no uncertainty about the input bin of the histogram. From the data processing inequality (2), any clustering or quantization over X or Y, respectively represented by $\widehat{X}$ and $\widehat{Y}$, will reduce the MI of the channel. Thus, $I(X,Y) \geq I(X,\widehat{Y})$ and $I(X,Y) \geq I(\widehat{X},Y)$.

From the above reasonings, a pixel clustering algorithm which minimizes the loss of MI could be proposed. However, its high cost suggests adopting the contrary strategy, where the full image is taken as the unique initial partition and is progressively subdivided according to the maximum MI gain for each partitioning step. This algorithm is a greedy top-down procedure which partitions an image in quasi-homogeneous regions. This method can be visualized from equation $H(X) = I(X,\widehat{Y}) + H(X|\widehat{Y})$, where the acquisition of information increases $I(X,\widehat{Y})$ and decreases $H(X|\widehat{Y})$, producing a reduction of uncertainty due to the equalization of the regions. Different stopping criteria can be used. For more details, see [5].

3 Registration from Partitioned Images

Registration aims to find a transformation which maps two or more images by optimizing certain similarity measure. Multiresolution and multisampling strategies can be used to reduce its computational cost by means of a coarse-to-fine hierarchical strategy which starts with the reference and floating images on a coarser resolution. The estimates of the correspondence or parameters of the mapping functions while going up to finer resolutions are progressively improved. At every level they considerably decrease the search space and thus save computational time. In particular, downsampling techniques cause a great acceleration of the registration process [4].

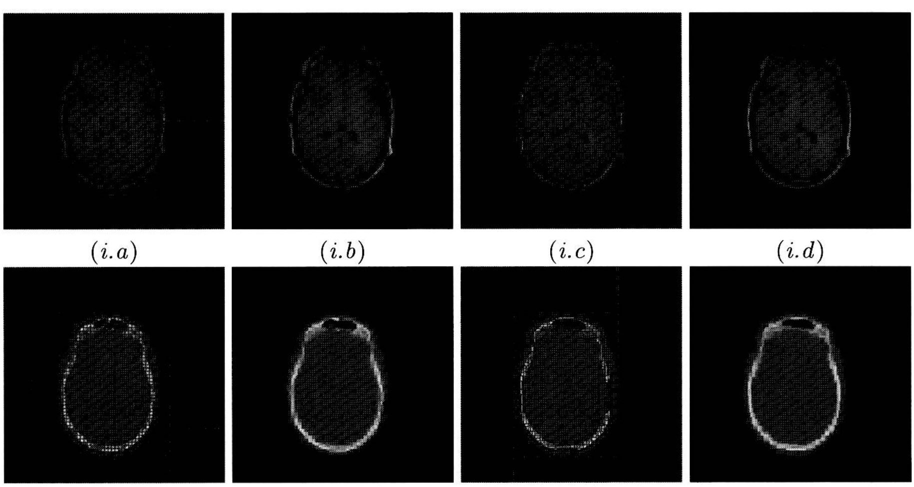


(*a*) MR (*b*) CT (*c*) MR (*d*) PET

Fig. 1. Test images from the Vanderbilt database [3]

Obviously, a good strategy to speed-up the registration process could be to use simplified images instead of the original ones. Our proposal is to register the images obtained with the MI-based partitioning algorithm presented in Sec. 2. These images contain a high information level for a reduced number of regions. This proposal is a first approximation for considering the benefits of a multiresolution approach which would consist in the interplay of the different resolutions of both images to accelerate registration. At each registration level, the best suited resolution for each image would be selected. Crucial to developing this multiresolution framework is the selection of the simplification strategy that has to be applied to simplify images. In this paper, we investigate two subdivision techniques, BSP and quadtree, to determine which provides better results.

To carry out this study, we propose a two step registration process. In the first step, the original images are progressively partitioned with vertical or horizontal



(*i.a*) (*i.b*) (*i.c*) (*i.d*)

(*ii.a*) (*ii.b*) (*ii.c*) (*ii.d*)

Fig. 2. (*i*) MR and (*ii*) CT images obtained from Fig. 1(*a*-*b*). (*a*) Quad-tree partitions with $MIR = 0.7$, (*b*) quad-tree simplified images, (*c*) BSP partitions with $MIR = 0.7$, and (*d*) BSP simplified images.